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Undestanding Stage of Change Transitions Across Multiple Behaviors

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UNDERSTANDING STAGE OF CHANGE TRANSITIONS ACROSS MULTIPLE BEHAVIORS

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ABSTRACT

Health behavior research reveals that individuals vary in their general readiness to change their behaviors, as well as their attitudes and beliefs about that change. Adolescents are an important population for health behavior change interventions because the choices and behaviors early in life can have long-term health impacts. A large (N=4158), school-based Transtheoretical Model (TTM) randomized trial evaluated two tailored, computer-delivered multiple behavior interventions designed to impact energy balance behaviors, including physical activity, fruit and vegetable consumption, and TV viewing, or substance use, including smoking and alcohol. The study took place over a four-year period, with intervention points during grades six through eight and a follow-up assessment in grade nine. Main outcomes from this study indicated that students in the energy balance intervention effectively initiated and maintained energy balance behaviors in addition to reducing smoking and alcohol acquisition, despite no direct treatment for smoking and alcohol prevention. To better elucidate the process of behavior change, and to inform future interventions on how students at different levels of readiness to change respond to the intervention in relation to a comparison condition, an examination of the patterns and transitions in stage change over time is warranted.

Latent transition analysis (LTA), a longitudinal latent variable method that models discrete change and is particularly useful for stage-sequential models, was employed to estimate the stage membership and transition probabilities across time for the five health behaviors. Three studies were completed to determine intervention effects on stage of change membership and transitions in middle school adolescents.

The first study examined intervention effects on stage of change membership and transitions among adolescent physical activity, fruit and vegetable consumption, and TV viewing. The second study examined intervention effects on stage of change membership and transitions among adolescent smoking and alcohol use acquisition. Finally, the third study examined gender differences in stage of change membership and transitions among adolescent physical activity and fruit and vegetable consumption across intervention conditions.

Overall results indicate intervention differences in stage membership and transitions for the five behaviors, as well as differential effects for males and females in stage membership and transitions for physical activity and fruit and vegetable consumption across intervention condition.

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PREFACE

This dissertation was prepared in manuscript format. The three manuscripts contained therein have been prepared in anticipation for submission to the following journals: Multivariate Behavioral Research (Manuscript 1), Addictive Behaviors (Manuscript 2), and the Annals of Behavioral Medicine (Manuscript 3).

The Appendix includes additional background, overview of the statistical methodology, and discussion.

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MANUSCRIPT 1

Intervention effects on stage of change membership and transitions among adolescent energy balance behaviors

Intended Journal for Submission: Multivariate Behavioral Research (not yet submitted)

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Abstract.

The transition from childhood to adolescence is a crucial period for the development of healthy behaviors to be sustained later in life. With obesity one of the leading public health problems, research focusing on promotion of healthy behaviors has the potential to make a huge public health impact. The current study evaluated Stage of Change progression in a large (N=4158) computer delivered, TTM-tailored multiple behavior intervention focusing on energy balance behaviors, including physical activity, fruit and vegetable consumption, and TV viewing. Assessments began in sixth grade and continued yearly until eighth grade with a follow-up in ninth grade. Latent Transition Analysis was used to explore stage transitions across each of the three behaviors with a focus on answering three primary research questions: (1) What is the pattern of stage movement over time; (2) Does intervention condition affect stage transitions?; and (3) Is the pattern of change consistent across behaviors? Major findings supported positive intervention effects for energy balance behaviors and significantly different patterns of change between intervention conditions, as well as substantial differences in stage membership and transitions across behavior.

Intervention effects on stage of change membership and transitions among adolescent energy balance behaviors

The transition from childhood to adolescence is a crucial period for the development of healthy behaviors to be sustained later in life. Research has found that that physical activity (Dumith, Gigante, Domingues, & Kohl, 2011) and the consumption of fruit and vegetables decreases (Lien, Lytle, & Klepp, 2001) as adolescents transition to young adulthood. Physical activity and fitness in adolescence, particularly aerobic fitness, has been linked to young adulthood cardiovascular disease risk factor level (Hasselstrøm, Hansen, Froberg, & Andersen, 2002). Research also suggests that decreases in fruit consumption, hours of physical education, and frequency of sports participation were associated with higher increases in standardized scores of Body Mass Index (Haerens, Vereecken, Maes, & De Bourdeaudhuij, 2010). Furthermore, adolescents are an important population for health behavior promotion, as behaviors related to obesity prevention have shown that being at risk for one unhealthy behavior tends to increase the odds of being at risk for another unhealthy behavior (Driskell, Dyment, Mauriello, Castle, & Sherman, 2008). Given that obesity is a leading public health problem, with 68.5% of adults being overweight or obese and 38.1% of children and adolescents being overweight or obesity in the United States (Ogden, Carroll, Kit, & Flegal, 2014), research focusing on promotion of healthy behaviors has the potential to make a huge public health impact.

Psychological research applying the Transtheoretical Model (TTM) has found that, in addition to their attitudes and beliefs about that change, people vary in their general readiness to change their behavior (Prochaska, 1983). Consequently, change is viewed as a temporal sequence of behavioral and cognitive modifications that individuals experience in their efforts to become healthier (Martin, Velicer, & Fava, 1996; Prochaska & Velicer, 1997; Velicer et al., 2000). Intentional behavior change is conventionally represented as a progression through the five ordered Stages of Change: Precontemplation (PC), Contemplation (C), Preparation (P), Action (A), and Maintenance (M) (Prochaska, Redding, & Evers, 2008; Prochaska & Velicer, 1997; Prochaska, Wright, & Velicer, 2008; Velicer et al., 2000). Stage progression is a dynamic process similar to a punctuated equilibrium model in which behavior can be characterized by long periods of stasis punctuated by periods of change. Behavioral interventions can serve to disrupt behavioral stasis and promote healthy change.

School-based energy balance interventions, which focus on diet, physical activity, and sedentary behavior, present vital opportunities for health promotion in young people. Unfortunately, energy balance interventions in adolescents are few and have been met with mixed success (De Bourdeaudhuij et al., 2010; Ezendam, Brug, & Oenema, 2012; Lubans, Morgan, Callister, & Collins, 2009; Patrick et al., 2006; van Stralen et al., 2011).

A recent school-based Transtheoretical Model (TTM) intervention found significant positive effects for a computerized energy balance program for middle school students (Velicer et al., 2013). The study developed two TTM-tailored, computer-delivered, multiple behavior interventions in middle school students. One intervention was designed to impact energy balance behaviors, including physical activity, fruit and vegetable consumption, and TV viewing, while the comparison intervention addressed substance use, including smoking and alcohol. The study's main outcomes found strong effects for change in energy balance behaviors. To better elucidate the process of behavior change, and to inform future interventions on how students at different levels of readiness to change respond to the intervention in relation to a comparison condition, an examination of the patterns and transitions in stage change over time is warranted.

Latent Transition Analysis

Latent transition analysis (LTA) is a longitudinal latent variable method that models discrete change among subgroups of participants and is particularly useful for stage-sequential models in which people progress through qualitative stages of change. These subgroups are considered to be dynamic statuses, or, in the context of the current study, stages of change that people may move in and out of over time. The basic LTA model estimates the proportion of individuals in each stage at every time point as well as the probability of transitioning to another stage at the next time point or remaining in the same stage (Collins & Lanza, 2010; Velicer, Martin, & Collins, 1996). Thus, LTA is a longitudinal extension of Latent Class Analysis (LCA), a cross-sectional latent variable measurement model using observed discrete variables to produce categorical latent classes (Collins & Lanza, 2010). In contrast to factor analysis, which produces a continuous latent variable by reducing dimensionality in the variable space, LCA reduces a population into mutually exclusive and exhaustive categorical subgroups. LTA builds off of LCA by predicting the probability of temporal movement among subgroups conditional on previous membership. In the context of determining longitudinal change in TTM-stage variables, LTA is an appropriate method due to the focus on discrete, rather than continuous, change.

The basic LTA model contains both a measurement and structural component. The measurement component characterizes the discrete latent classes and the structural component determines the probabilities of status membership and transition. The structural component relies on autoregressive techniques to acknowledge a stochastic process in which repeated measures are linearly dependent on their own previous values. Three sets of parameters are estimated in LTA: latent status prevalences (δ), transition probabilities (τ), and item-response probabilities (ϱ). δ estimates represent the proportion of status membership at time *t*. Latent statuses are mutually exclusive and exhaustive such that every individual is placed in only one group at each time point. τ estimates represent the probability of transitioning to a given status at time *t,* conditional on status at time *t-1* (for a first order model). The τ parameters reveal the underlying pattern of change and elucidate stage progression, regression, or stability. Finally, ϱ estimates represent the probability of a response for a particular item, conditional on latent class membership at a specific time point. Thus, similar to factor loadings in structural equation modeling, ϱ's form the basis of latent status separation as they are used to indicate patterns of responses among discrete variables across time based on latent status membership. Unlike factor loadings, however, ϱ's are probabilities and are scaled differently. Values close to 0 or 1 indicate latent status membership while values that are close to one divided by the number of response patterns indicates chance (Velicer, Martin, & Collins, 1996).

Few studies have examined TTM Stage of Change using LTA and much of this research has focused on stages of change for smoking cessation in adults (Guo, Aveyard, Fielding, & Sutton, 2009; Martin et al., 1996; Schumann, Meyer, Rumpf, Hapke, & John, 2002). Even fewer have examined the effects of a behavioral intervention on stage transitions (Schumann, John, Rumpf, Hapke, & Meyer, 2006) or classification of other behaviors, like physical activity (Dishman et al., 2009) or condom use (Evers, Harlow, Redding, & LaForge, 1998). Therefore, an examination of the stage of change transitions with LTA applied to novel behaviors will serve to inform and contribute to the overarching understanding of single and multiple health behavior change.

The current study focuses on patterns of TTM stage change across time, behavior, and intervention condition by examining probabilities of stage membership and transitions for physical activity, fruit and vegetable consumption, and TV viewing in a multiple behavior health intervention. LTA is used to explore longitudinal stage transitions in each intervention group across each of the three behaviors over the course of the study. LTA also provides a model-comparison framework that promotes informed and specific hypothesis testing. Thus, the primary research questions addressed are threefold: (1) What is the pattern of stage movement over time; (2) Does intervention condition affect stage transitions?; and (3) Is the pattern of change consistent across behaviors?

Methods

Sample

Students (N=4158) from 20 middle schools across Rhode Island were 47.8%

female, 65.0% white, 15.6% Hispanic, 3.8% Black, 2.4% Asian, 2.2% American Indian/Alaskan Native, 0.5% Pacific Islander, and the remaining were unknown or a combination of ethnicities. Students were randomized by school, which were matched on available school-level data (e.g. percent free lunch eligible, percent English as second language, percent attending college, racial/ethnic composition, smoking rate, and alcohol use rate) and assigned to either the energy balance intervention or a comparison intervention, described below.

Intervention design

Ten schools received an energy balance intervention, and ten schools in the comparison intervention received a comparison intervention. The primary focus for the energy balance intervention was to increase or sustain physical activity and fruit and vegetable consumption, as well as reduce TV viewing. The primary focus for the comparison intervention was to prevent substance use acquisition for students who were not smokers or alcohol users, or to provide support and cessation information if they were. Each intervention was highly tailored based on TTM constructs (Redding et al., 1999; Velicer et al., 2013) and each intervention condition served as the comparison condition for the other, with both receiving comparable assessments and TTM-tailored intervention feedback using multimedia component for multiple behaviors. However, students in the energy balance intervention did not receive feedback on substance use behaviors and students in the comparison intervention did not receive feedback on energy balance behaviors. Each intervention was disseminated through five 30-minute computerized TTM-tailored sessions including one in sixth grade, three in seventh grade, and one in eighth grade. A total of four assessments were completed by students in each condition early in each school year of the project (sixth, seventh, eighth, and ninth grades). For more detail regarding study design and outcomes, see Velicer et al. (2013).

Measures

The current study focuses on answering the primary research questions with respect to stage transitions for three energy balance behaviors, including physical activity, fruit and vegetable consumption, and TV viewing. The Stage of Change algorithm that was used for each of the energy balance behaviors has been previously validated (Mauriello et al., 2010). Criteria for Stage of Change is as follows: (1) Precontemplation (PC; not meeting behavioral criteria and not planning to meet criteria in the next 6 months), (2) Contemplation (C; not meeting behavioral criteria but planning to meet criteria in the next 6 months), (3) Preparation (PR; not meeting behavioral criteria but planning to meet criteria in the next 30 days), (4) Action (A; meeting behavioral criteria for less than 6 months), and (5) Maintenance (M; meeting behavioral criteria for more than 6 months). Collectively, PC, C, and PR are considered "pre-action" stages, as they represent levels of readiness to change before action has been taken to modify behavior,

To prevent stage misclassification, the staging algorithm used verification with specific behavioral criteria prior to asking about behavior intention. Specific criteria for each behavior was as follows: (a) physical activity (at least 60 min of physical activity for at least 5 days per week), (b) fruit and vegetable consumption (at least five servings of fruits and vegetables each day), and (c) limited TV viewing (2 hours or less of TV time each day). For example, if a participant did not report engaging in 60 minutes of physical activity at least five days a week, they were asked about their intention to being engaging in physical activity and could not be considered in A or M.

Statistical Analyses

All statistical analyses were conducted in SAS version 9.3 using the SAS Macro for PROC LTA (PROC LCA & PROC LTA [Version 1.3.0], 2013). The full information maximum likelihood technique accounted for missing data due to attrition or missed school days when data was collected. Model fit was assessed using a number of criteria. The Goodness of Fit statistic G^2 is approximately distributed as a χ^2 and can be used to compare alternative models (Collins & Lanza, 2010; Velicer et al., 1996). Nested models were compared using log likelihood ratio G^2 difference tests, which were calculated by the differences in G^2 of two competing models relative to their difference in degrees of freedom. Due to known limitations of the chi-squared distribution with large sample sizes, the Akaike Information Criteria (Akaike, 1973) and the Bayesian Information Criteria (Schwarz, 1978) were also used to decide the best and most parsimonious model. However, many of these criteria tend to favor model complexity, thus the concept of model parsimony will also be used to help guide the decision.

In addition, the authors acknowledge that the phrasing used in this study applies the term “equivalent” to mean “no evidence of statistical differences”. The model comparison approach is used to test for significant changes in model fit when parameters are constrained to equality supports evidence for relatively equal parameter estimates. Further, given the complexity of these models, a brief note on the terminology of model parameters is warranted. LTA involves the estimation of three types of parameters: delta (the stage membership probability), tau (the transition probability, conditional on previous stage membership), and rho (the item-response probability for a given stage). The study took place over a four-year period beginning in sixth grade, with annual assessments and a follow-up assessment administered without intervention material in ninth grade. Thus, three transition periods are the main focus of the study, representing the transition between sixth and seventh grade, the transition between seventh and eighth grade, and the transition between eighth and ninth grade. See Figure 1 for a visual depiction of the study flow and corresponding parameter estimates.

Three overarching types of model comparison tests were assessed. First, intervention specific stage movement patterns examined model parameters for each intervention condition separately for the three behaviors. Then, intervention effects on transition parameters examined model parameters using separate multiple-group models for the three behaviors with intervention as a grouping variable. Finally, behavior was entered as a grouping variable and multiple group models were used to determine equivalence of parameters across behavior for each intervention condition.

Start values and parameter restrictions. In order to conduct model comparison tests, matrices containing start values and parameter restrictions are specified for model convergence. Syntax for these matrices is available upon request. The rho matrices for all models are identical, with values fixed to invariance across time and all matrices present each stage as a single item indicator for each status.

Intervention specific stage movement patterns. To determine the best pattern of stage movement, as well as to determine the stability of patterns over time, transition models were compared separately for each behavior within each intervention condition. First, a freely estimated transition model was estimated (Model 1) with no restrictions on delta or tau matrices. Next, nested models with increasingly constrained tau matrices were compared with the free model to determine the best fitting pattern of stage movement. Model 2 restricted tau matrices to three or less stages forward and backward stage movement, Model 3 restricted to two or less forward and backward, Model 4 restricted to two or less forward and one backward, and Model 5 restricted to one forward and one backward.

To determine the stability of transition parameters, models with successive tau matrices held equivalent were compared to the freely estimated model (Model 1). Model 6 held transition parameters from grades six to seven equivalent to grades seven to eight, Model 7 held parameters from grades seven eight equivalent to grades eight to nine, and Model 8 held parameters from grades six to seven equivalent to grades eight to nine. If any two transitions were found equivalent, a follow-up model (Model 9) added the third transition to test for equivalence across all grades.

Intervention effects on transition parameters. Similar to the approach above, a series of nested models were compared to determine the equivalence of model parameters across intervention condition for each behavior. First, a freely estimated multiple-group model (Model 1) was compared with nested models containing increasingly constrained parameter restrictions. Next, sixth grade delta parameters were constrained to be equal across group (Model 2) to determine equivalence of stage distribution for the baseline assessment. Then, to identify which of the transition periods demonstrated differences in parameters estimates, each of the tau matrices for the three transition matrices were held equivalent across group (Model 3 for grades 6-7, Model 4 for grades 7-8, and Model 5 for grades 8-9). Finally, a parsimonious model (Model 6) was tested that integrate findings from both approaches (i.e. within intervention models and across intervention models) by holding some transitions across time and across intervention condition equivalent to represent a final, reduced model.

Parameter equivalence across behaviors. Finally, similar to the approach above, a series of nested models were compared to determine the equivalence of model parameters across behaviors. Each behavior was compared to another behavior for a total of three sets (e.g. physical activity vs. fruit and vegetable consumption, physical activity vs. TV viewing, fruit and vegetable consumption vs. TV viewing). First, a freely estimated multiple-group model (Model 1) was compared with nested models containing increasingly constrained parameter restrictions. Next, baseline delta parameters were constrained to be equal across group (Model 2) to determine equivalence of stage distribution for the baseline assessment. Then, to identify which transition periods demonstrated differences in parameters estimates, each of the tau matrices for the three transitions were held equivalent across group (Model 3 for the first transition matrix, Model 4 for the second transition, and Model 5 for the third transition).

Results

Model estimated stage membership probabilities in the free transition model across are presented in Table 1. The energy balance intervention consisted of 2,184 students and the comparison intervention consisted of 1,974 students. In sixth grade, about half of the students were in M for physical activity, and about one quarter of students were in M for fruit and vegetable consumption and one quarter were in M for TV viewing.

Physical Activity

Intervention specific stage movement patterns. See Table 2 for results of stage movement pattern models specific to each intervention condition for physical activity stages. In the energy balance intervention, significant ΔG^2 values and an increase in AIC and BIC reveal that the free stage movement model (Model 1) was favored over more restricted movement models (Models 2-5). Models with transition matrices held successively equivalent (Models 6-9) demonstrated that, compared to the free transition model (Model 1), parameter estimates in each of the three transitions were significantly different across grades six through nine. For the comparison intervention, a free transition model (Model 1) was also favored over more restricted transition models (Models 2-5). Unlike the energy balance intervention, however, models with successive transition matrices held equivalent across all grades (Models 6-9) revealed that fit did not significantly decrease compared to the free transition model. Thus the transition matrices can be considered to be consistent across time in the comparison condition but not the intervention condition.

Intervention effects on transition parameters. Table 3 presents fit indices for multiple-group models testing equivalence of parameters across intervention condition. When delta parameters were held equivalent for Physical activity in sixth grade (Model 2), G^2 did not significantly change and the AIC and BIC values dropped, signifying that baseline stage distribution was equivalent across intervention group. When transitions were held equivalent from grades six to seven (Model 3), as well as for grades seven through eight (Model 4), G^2 significantly changed and AIC and BIC values increased. However, significant change in model fit was not observed when transitions from grades eight to nine (Model 5) were held equivalent across groups. This suggests intervention differences between conditions from grades six to eight that disappeared after the conclusion of the intervention during the transition into ninth grade.

A final, parsimonious model (Model 6) was subsequently compared to the free model with equivalent sixth grade delta parameters (Model 2). The restrictions in this model were based on the findings from the within group transition models across time and the multiple group models across intervention condition. See Figure 3 for a summary of equivalence findings from models estimated across time and intervention condition. In the optimized model, transition matrices within the energy balance intervention were allowed to vary across time, transition matrices within the comparison intervention were constrained to equivalence across time, and the transition parameters across intervention condition for grades eight to nine were constrained to equivalence while the transition parameter across intervention condition for grades six to eight were allowed to vary. Though the G^2 significantly increased relative to Model 2, both the AIC and the BIC were at their lowest. Given the complexity of these models, parameter estimates for the intervention condition in this parsimonious model are displayed in Table 4, with differences from the comparison intervention displayed below intervention parameter estimates in parenthesis. Figures

4, 5, and 6 present parameter estimates for each transition period in the optimized model to facilitate understanding. In these depictions, probabilities of staying a stage are presented inside circles, and probabilities of transitioning are presented along solid (for forward transitions) or dashed (for backward transitions) lines. Difference values in parameter estimates from the comparison condition are presented below estimates from the intervention condition.

An examination of the transition estimates reveals that in the comparison condition, no participants transitioned from pre-action stages (PC, C, and PR) to M during any of the transitions. Participants in the intervention condition did, however, transition from pre-action stages to M, but only during transitions from sixth to eighth grade. The probability of transitioning into M from any of the other stages was consistently higher across all grades in the intervention condition. Backwards transitions were generally lower in the intervention condition, though the differences were fairly small.

Fruit and Vegetable Consumption

Intervention specific stage movement patterns. See Table 5 for model results of stage movement pattern models specific to each intervention condition. For the energy balance intervention, significant ΔG^2 and an increase in AIC and BIC reveal that the free stage movement model (Model 1) was favored over more restricted movement models (Models 2-5). Next, models with successive transition matrices held equivalent (Models 6-9) demonstrated that parameter estimates in each of the three transitions were significantly different when compared with the freely estimated model (Model 1). For the comparison intervention, a free transition model (Model 1) was favored over more restricted transition models (Models 2-5). Unlike the energy balance intervention, however, models with successive transition matrices held equivalent (Models 6-9) revealed that fit did not significantly decrease compared to the free transition model. Thus the transition matrices can be considered to be consistent across time in the comparison condition but not the intervention condition.

Intervention effects on transition parameters. Refer to Table 3 for a presentation of fit indices from multiple-group models testing equivalence of parameters across intervention condition for all three behaviors. For Fruit and Vegetable Consumption, when delta parameters were held equivalent for sixth grade (Model 2), G^2 significantly changed and the AIC increased, suggesting that baseline stage distribution may not be equivalent across intervention group. An examination of delta parameters from Table 1 reveals that student in the comparison intervention had a slightly higher probability of being in PC (~15%) than the intervention condition (~12%), and a slightly lower probability of being in C (~20%) than the intervention condition (~23%). Though these differences are not of a large magnitude, delta parameters for subsequent models were allowed to vary across groups. When transitions were held equivalent from grades six to seven (Model 3), as well as from grades seven to eight (Model 4), G^2 significantly changed and AIC and BIC values increased. However, significant change in model fit was not observed when transitions from grades eight to nine (Model 5) was held equivalent across groups. This suggests intervention differences from grades six to eight that disappeared after the conclusion of the intervention during the transition into ninth grade.

A final, parsimonious model (Model 6) was subsequently compared to the free model with equivalent sixth grade delta parameters (Model 2). The restrictions in this model were based on the findings from the within group transition models across time and the multiple group models across intervention condition and were consistent with the pattern observed for physical activity (see Figure 2 for a summary). Thus, transition matrices within the energy balance intervention were allowed to vary across time, transition matrices within the comparison intervention were constrained to equivalence across time, and the transition parameters across intervention condition for grades eight to nine were constrained to equivalence while the transition parameter across intervention condition for grades six to eight were allowed to vary. In this model G^2 significantly increased relative to Model 2, the AIC increased, but the BIC was at its lowest. Given the complexity of these models, parameter estimates for the intervention condition in this parsimonious model are displayed in Table 6, with differences from the comparison intervention displayed below in parenthesis. Figures 7, 8, and 9 present parameter estimates for each transition period in the optimized model to facilitate understanding.

An examination of these estimates reveals that in the comparison condition, no participants transitioned from pre-action stages (PC, C, and PR) to M during any of the transitions. Participants in the intervention condition did, however, transition from pre-action stages to M, but only during transitions from sixth to eighth grade. The probability of transitioning into M from any of the other stages was consistently higher across all grades in the intervention condition. Backwards transitions were generally lower in the intervention condition, though the differences were fairly small.

TV viewing

Intervention specific stage movement patterns. See Table 7 for model results of stage movement pattern models specific to each intervention condition. For the energy balance intervention, significant ΔG^2 and an increase in AIC and BIC values reveal that the free stage movement model (Model 1) was favored over more restricted movement models (Models 2-5). Then, models with successive transition matrices held equivalent (Models 6-9) demonstrated that parameter estimates in each of the three transitions were significantly different across grades six through nine. For the comparison intervention, the free transition model (Model 1) was also favored over more restricted stage movement models (Models 2-5). Unlike the energy balance intervention, however, models with successive transition matrices held equivalent across all grades (Models 6-9) revealed that fit did not significantly decrease compared to the free transition model. Thus the transition matrices can be considered to be consistent across time in the comparison condition but not the intervention condition.

Taken together, these findings demonstrate that a free stage movement pattern model tend to be favored for both interventions. However, in the energy balance intervention transition parameter patterns appear to be nonequivalent across grades six through nine while transitions in the comparison condition were.

Intervention effects on transition parameters. See Table 3 for a presentation of fit indices from multiple-group models testing equivalence of parameters across intervention condition for all three behaviors. For TV Viewing, when delta parameters were held equivalent for sixth grade (Model 2), G^2 significantly changed and the AIC slightly increased, suggesting that baseline stage distribution may not be equivalent across intervention group. An examination of delta parameters from Table 1 reveals that student in the comparison intervention had a slightly higher probability of being in PC (~32%) than the intervention condition (~27%), and a slightly lower probability of being in M (~24%) than the intervention condition (~26%). Though these differences are not of a large magnitude, delta parameters for subsequent models were allowed to vary across groups. When transitions were held equivalent from grades six to seven (Model 3), as well as from grades seven to eight (Model 4), G^2 significantly changed and AIC and BIC values increased. However, significant change in model fit was not observed when transitions from grades eight to nine (Model 5) was held equivalent across groups. This suggests intervention differences from grades six to eight that disappeared after the conclusion of the intervention during the transition into ninth grade.

A final, parsimonious model (Model 6) was subsequently compared to the free model with equivalent sixth grade delta parameters (Model 2). The restrictions in this model were based on the findings from the within group transition models across time and the multiple group models across intervention condition and were consistent with the pattern observed for physical activity and fruit and the pattern observed for vegetable consumption (see Figure 2 for a summary). Thus, transition matrices within the energy balance intervention were allowed to vary across time, transition matrices within the comparison intervention were constrained to equivalence across time, and the transition parameters across intervention condition for grades eight to nine were constrained to equivalence while the transition parameter across intervention condition for grades six to eight were allowed to vary. In this model G^2 significantly increased relative to Model 2, the AIC increased, but the BIC was at its lowest. Given the complexity of these models, parameter estimates for the intervention condition in this parsimonious model are displayed in Table 8, with differences from the comparison intervention displayed below in parenthesis. Figures 10, 11, and 12 present parameter estimates for each transition period in the optimized model to facilitate understanding.

An examination of these estimates reveals that in the comparison condition, no participants transitioned from pre-action stages (PC, C, and PR) to M during any of the transitions. Participants in the intervention condition did, however, transition from pre-action stages to M, but only during transitions from sixth to eighth grade. The probability of transitioning into M from any of the other stages was consistently higher across all grades in the intervention condition. Backwards transitions were generally lower in the intervention condition, though the differences were fairly small.

Parameter equivalence across behaviors

Results from model comparison are presented in Tables 9 and 10 for the energy balance and comparison interventions, respectively. Findings indicate that fit significantly worsened (significant change in G^2 and an increase in both AIC and BIC), indicating differences in baseline stage membership for all behavior comparisons. In addition, Models 2-5 for all behavior comparisons demonstrated significant worsening of model fit when transition parameters were constrained to equality across groups. Taken together, these findings suggest that different behaviors have unique patterns of stage change over time. Differences for transition probabilities across behaviors, however, did not exceed 0.30 and tended to be lower than 0.20.

Discussion

This study is the first to systematically examine stage transitions in three energy balance behaviors across time, intervention, and behavior. For all behaviors, a freely estimated transition model was favored when compared to one, two-, or three-stage movement patterns. Given this finding, and considering that measurements were taken at yearly intervals, it is evident that a considerable amount of stage movement may be occurring between intervention assessments. The finding that models in which participants progress three or more stages between time points is consistent with some previous research that also favored models with higher numbers of stage transitions for smoking behavior with measures taken at yearly intervals (Schumann et al., 2006). Previous research with data taken at shorter intervals (i.e. six month) favored more restricted models with one- or two- stage movement patterns (Martin et al., 1996; Schumann et al., 2002). This is not surprising, considering that some stage movement patterns are constrained by the time requirements needed for an individual to be characterized in the A or M stages (i.e. the individual must maintain specific behavior at recommended criteria for less than or greater than six months, respectively). An examination of transition probabilities from the freely estimated model reveals that there were higher probabilities of staying in the same stage than transitioning, due to higher values on the diagonals of the tau matrix, and that the probability of stage movement beyond one or two stages was very low.

In addition, for all behaviors, transition patterns over time in the energy balance intervention appear to vary across grades six through nine while transitions in the comparison condition remained similar over time. This supports the notion that the pattern of transitions did not change much in the comparison intervention, representing a relatively stable and unchanging pattern, while the intervention condition resulted in dynamic and changing transition probabilities. Ideally, an intervention should promote positive change (i.e. towards M) and prevent negative change (i.e. movement towards PC).

Intervention effects on stage transitions for all behaviors resulted in different transitions across intervention condition from grades six through eight, but transitions from grades eight to nine were not different from the comparison intervention. This suggests that intervention effects declined after the end of the intervention in eighth grade. Further, no students in the comparison intervention transitioned from pre-action stages to M for any of the behaviors. This pattern was also present in the intervention group, after eighth grade, which coincides both with the conclusion of the intervention and with the transition from middle to high school. This finding provides evidence for the success of the intervention condition in promoting stage progression into M during the intervention, but also suggests that the effect diminishes after the intervention concludes. However, the underlying reasons for this finding may be confounded, as these changes may be due in part to a decline in intervention effects from the cessation of the intervention but may also be due to changes in lifestyle, environment, and behavior associated with the transition from middle school to high school. For example, students who played athletics in middle school may not play in high school, thereby resulting in a reduction in physical activity. Similarly, the transition to high school may also contain diet changes, as students in high school have more independence and diverse options for choices for lunch and snacks throughout the day.

Finally, when multiple group models were examined to determine if stage membership and transitions were similar across behaviors for each intervention condition, all models demonstrated nonequivalence, suggesting that the pattern of change varies considerable across behavior. Each behavior exhibited unique baseline stage distribution, with students having a higher probability of being in M for exercise, high probabilities of being in PR, followed by C and M for fruit and vegetable consumption, and high probabilities of being in PC or M for TV viewing.

Limitations and Future Directions

A major limitation to this study is the lack of a true no-treatment control group that would provide an indication of normative or natural change. This limitation is also described in the original study, which highlights the choice in a two-treatment control comparison trial as more cost effective, maximized school participation, and met curriculum demands of participating schools (Velicer et al., 2013). The current study also does not take into consideration the clustering of individuals within schools. Future studies may benefit from taking school-level information into account using LTA. Finally, the LTA model in this study modeled in such a way that each stage is a manifest variable indicated by a single item (i.e. the result of the staging algorithm). Thus the model itself does not contain measurement error. Future studies may consider using multiple measures to determine stage of change in order to incorporate measurement error and represent truly "latent" statuses.

Another noteworthy limitation lies in interpreting model comparison results due to a lack in a good index of model fit. Currently available fit indices, such as the AIC and BIC, have been criticized for their assumptions and reliability in real world data (Dziak, Coffman, Lanza, & Li, 2012) and tend to favor more complex models. Due to the nature of LTA, the models tested in this paper all contained extremely large numbers of estimated parameters. It is largely unknown how robust these indices (i.e. G^2, AIC, BIC) are with complex LTA models.

Future studies should focus on increasing the probabilities of staying in or transitioning into A or M and decreasing the probability of staying in or transitioning into PC. Given the tendency for high probabilities for staying in PC, but low tau probabilities for transitioning into PC, interventions may strive to identify individuals who consistently remain in pre-action stages to tailor the intervention to their specific needs. For example, someone who is not ready to change and remains that way consistently may have different needs than an individual with a more unstable stage membership pattern. Similarly, a person who is unstable in A or M may need more feedback or help than a person who is consistently in M. In this way, interventions may be developed to be sensitive not only to whether a person is ready to change at a given time, but also to whether they tend to remain that way or fluctuate in their readiness. Future studies could also examine covariate effects of gender, socioeconomic status, and race/ethnicity, as known differences in physical activity and diet behaviors exist for many demographic subgroups.

The analytic approach presented in this work can be easily extended and applied to other stage-sequential models or other types of behaviors. It allows for simultaneous estimation of all probabilities and a clearer focus on the process of change. This focus is placed on model comparisons across time by comparing successive transition probabilities within the model, as well as comparing membership and transitions across intervention condition. The model-comparison approach also highlights the formulations of hypotheses for specific model parameters within and across multiple groups, facilitating a comprehensive way to test and compare transition models.

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Tables and Figures

Table 1. Model estimated stage membership probabilities for energy balance behaviors.

Behavior	Time point	PC	C	PR	A	M
Energy Balance Intervention						
Physical Activity	6th grade	0.08	0.13	0.22	0.09	0.48
	7th grade	0.05	0.13	0.21	0.19	0.42
	8th grade	0.06	0.12	0.21	0.12	0.50
	9th grade	0.06	0.14	0.17	0.19	0.44
Fruit and Vegetable Consumption	6th grade	0.12	0.23	0.34	0.03	0.27
	7th grade	0.10	0.21	0.33	0.16	0.20
	8th grade	0.12	0.20	0.31	0.07	0.30
	9th grade	0.14	0.24	0.30	0.11	0.20
TV Viewing	6th grade	0.27	0.14	0.12	0.20	0.27
	7th grade	0.22	0.12	0.10	0.25	0.31
	8th grade	0.23	0.09	0.07	0.22	0.40
	9th grade	0.24	0.09	0.05	0.26	0.35
Comparison Intervention						
Physical Activity	6th grade	0.07	0.13	0.24	0.07	0.49
	7th grade	0.09	0.15	0.19	0.20	0.37
	8th grade	0.12	0.12	0.21	0.18	0.37
	9th grade	0.11	0.16	0.20	0.18	0.35
Fruit and Vegetable Consumption	6th grade	0.15	0.20	0.35	0.04	0.25
	7th grade	0.20	0.23	0.32	0.14	0.12
	8th grade	0.24	0.24	0.29	0.11	0.11
	9th grade	0.24	0.26	0.28	0.12	0.10
TV Viewing	6th grade	0.32	0.15	0.11	0.18	0.24
	7th grade	0.34	0.11	0.08	0.27	0.20
	8th grade	0.36	0.07	0.05	0.30	0.22
	9th grade	0.37	0.08	0.05	0.27	0.23

Note: PC = Precontemplation; C= Contemplation; PR= Preparation; A = Action; M = Maintenance.

Table 2. Model fit statistics for stage movement patterns within intervention condition for Physical Activity.

Stage Movement Pattern	**DF**	**-LL**	**G^2**	**ΔG^2**	**AIC**	**BIC**
Energy Balance Intervention						
Model 1: All free	1048511	-8996.99	591.51	--	719.51	1083.60
Model 2: Three-forward, three-backward	1048517	-9591.16	1779.86	1188.35*	1895.86	2225.81
Model 3: Two-forward, two-backward	1048529	-11727.02	6051.59	5460.08*	6143.59	6405.28
Model 4: Two-forward, one-backward	1048538	-14974.01	12545.57	11954.06*	12619.57	12830.06
Model 5: One-forward, one-backward	1048547	-18360.35	19318.25	18726.74*	19374.25	19533.53
Model 6: Tau grades 6-7 vs. 7-8 equal	1048531	-9041.87	681.27	89.76*	769.27	1019.59
Model 7: Tau grades 6-7 vs. 8-9 equal	1048531	-9139.60	876.74	285.23*	964.74	1215.05
Model 8: Tau grades 7-8 vs. 8-9 equal	1048531	-9123.27	844.09	252.58*	932.09	1182.40
Model 9: Tau grades 6-9 equal	1048551	-9191.98	981.51	300.24*	1029.51	1166.05
Comparison Intervention						
Model 1: All free	1048511	-7878.66	524.53	--	652.53	1010.15
Model 2: Three-forward, three-backward	1048517	-8297.59	1362.39	837.86*	1478.39	1802.48
Model 3: Two-forward, two-backward	1048529	-10527.14	5821.50	5296.97*	5913.50	6170.54
Model 4: Two-forward, one-backward	1048538	-13854.96	12477.15	11952.62*	12551.15	12757.90
Model 5: One-forward, one-backward	1048547	-16378.59	17524.40	16999.87*	17580.40	17736.85
Model 6: Tau grades 6-7 vs. 7-8 equal	1048531	-7893.39	554.01	29.48	642.01	887.87
Model 7: Tau grades 6-7 vs. 8-9 equal	1048531	-7889.76	546.74	22.21	634.74	880.61
Model 8: Tau grades 7-8 vs. 8-9 equal	1048531	-7890.07	547.36	22.83	635.36	881.22
Model 9: Tau grades 6-9 equal	1048551	-7903.71	574.64	20.63	622.64	756.75

Note: -LL = log likelihood; AIC = Akaike information criterion; BIC = Bayesian information criterion; DF = degrees of freedom; * = $p<0.05$; for ΔG^2, all models compared to Model 1 of respective condition (except Model 9, which is compared to Model 6).

Table 3. Model fit results for stage movement across intervention condition for energy balance behaviors.

Behavior	Pattern	DF	-LL	G^2	ΔG^2	AIC	BIC
Physical Activity	Model 1: All free	2097023	-16875.64	1116.05	--	1372.05	2182.64
	Model 2: Delta equal at baseline	2097027	-16878.81	1122.37	3.17	1370.37	2155.64
	Model 3: Tau grades 6-7 equal	2097047	-17055.09	1474.93	176.28*	1682.93	2341.54
	Model 4: Tau grades 7-8 equal	2097047	-17022.86	1410.49	144.05*	1618.49	2277.10
	Model 5: Tau grades 8-9 equal	2097047	-16897.73	1160.22	18.92	1368.22	2026.83
	Model 6: Parsimonious	2097090	-16933.80	1232.35	109.98*	1354.35	1740.65
Fruit and Vegetable Consumption	Model 1: All free	2097023	-18707.69	1204.86	--	1460.86	2271.46
	Model 2: Delta equal at baseline	2097027	-18714.43	1218.35	13.49*	1466.35	2251.62
	Model 3: Tau grades 6-7 equal	2097043	-18876.12	1541.73	692.47*	1757.73	2441.67
	Model 4: Tau grades 7-8 equal	2097043	-18864.35	1518.20	313.34*	1734.20	2418.14
	Model 5: Tau grades 8-9 equal	2097043	-18717.12	1223.72	18.86	1439.72	2123.66
	Model 6: Parsimonious	2097086	-18102.09	1377.97	173.11*	1507.97	1919.60
TV Viewing	Model 1: All free	2097023	-18040.27	1254.32	--	1510.32	2320.92
	Model 2: Delta equal at baseline	2097027	-18046.69	1267.17	12.85*	1515.17	2300.43
	Model 3: Tau grades 6-7 equal	2097043	-18169.19	1512.15	514.4*	1728.15	2412.10
	Model 4: Tau grades 7-8 equal	2097043	-18144.45	1462.67	208.35*	1678.67	2362.61
	Model 5: Tau grades 8-9 equal	2097043	-18055.21	1284.19	29.87	1500.19	2184.13
	Model 6: Parsimonious	2097086	-18102.09	1377.97	110.80*	1507.97	1919.60

Note: -LL = log likelihood; AIC = Akaike information criterion; BIC = Bayesian information criterion; DF = degrees of freedom; * = $p<0.05$; for ΔG^2, all models compared to Model 1 of respective condition (except Model 6, which is compared to Model 2 for physical activity).

Table 4. Transition parameters from parsimonious model for Physical Activity stages.

		PC	C	PR	A	M
		Stage in 7th Grade				
Stage in 6th Grade	**PC**	0.24	0.21	0.21	0.17	0.18
		(-0.20)	*(+0.03)*	*(+0.08)*	*(-0.09)*	*(+0.18)*
	C	0.06	0.25	0.27	0.22	0.19
		(-0.05)	*(-0.05)*	*(+0.05)*	*(-0.14)*	*(+0.19)*
	PR	0.03	0.15	0.35	0.23	0.23
		(-0.04)	*-0.04)*	*(0.00)*	*(-0.15)*	*(+0.23)*
	A	0.05	0.18	0.20	0.26	0.31
		(-0.04)	*(+0.03)*	*(-0.02)*	*(+0.15)*	*(-0.12)*
	M	0.02	0.07	0.13	0.16	0.62
		(-0.01)	*(+0.01)*	*(+0.01)*	*(+0.11)*	*(-0.12)*
		Stage in 8th Grade				
Stage in 7th Grade	**PC**	0.42	0.16	0.13	0.08	0.21
		(-0.02)	*(-0.02)*	*(+0.01)*	*(-0.18)*	*(+0.21)*
	C	0.09	0.32	0.24	0.19	0.17
		(-0.03)	*(+0.01)*	*(+0.02)*	*(-0.17)*	*(+0.17)*
	PR	0.03	0.15	0.42	0.16	0.24
		(-0.04)	*(-0.04)*	*(+0.06)*	*(-0.23)*	*(+0.24)*
	A	0.05	0.11	0.20	0.14	0.51
		(-0.04)	*(-0.04)*	*(-0.02)*	*(+0.02)*	*(+0.08)*
	M	0.02	0.04	0.10	0.07	0.77
		(-0.01)	*(-0.02)*	*(-0.01)*	*(+0.02)*	*(+0.03)*
		Stage in 9th Grade				
Stage in 8th Grade	**PC**	0.44	0.18	0.12	0.26	0.00
	C	0.12	0.31	0.22	0.36	0.00
	PR	0.07	0.19	0.36	0.39	0.00
	A	0.09	0.15	0.22	0.12	0.43
	M	0.03	0.06	0.11	0.05	0.74

Note: PC = Precontemplation; C= Contemplation; PR= Preparation; A = Action; M = Maintenance; values in parentheses represent the difference in the above parameter estimate from the comparison intervention.

Table 5. Model fit statistics for stage movement patterns within intervention condition for Fruit and Vegetable Consumption.

Stage Movement Pattern	DF	-LL	G^2	ΔG^2	AIC	BIC
Energy Balance						
Model 1: All free	1048511	-9866.70	679.46	--	807.46	1171.55
Model 2: Three-forward, three-backward	1048517	-10478.70	1903.46	1224.00*	2019.46	2349.42
Model 3: Two-forward, two-backward	1048529	-11422.35	5688.13	5008.67*	5780.13	6037.17
Model 4: Two-forward, one-backward	1048538	-16480.18	13906.42	13226.96*	13980.42	14190.91
Model 5: One-forward, one-backward	1048547	-19783.23	20512.50	19833.04*	20568.50	20727.79
Model 6: Tau grades 6-7 vs. 7-8 equal	1048531	-9949.35	844.74	165.28*	932.74	1183.06
Model 7: Tau grades 6-7 vs. 8-9 equal	1048531	-10008.01	962.07	282.61*	1050.07	1300.38
Model 8: Tau grades 7-8 vs. 8-9 equal	1048531	-9993.35	932.74	253.28*	1020.74	1271.06
Model 9: Tau grades 6-9 equal	1048551	-10087.58	1121.20	276.46*	1169.20	1305.74
Comparison Intervention						
Model 1: All free	1048511	-8840.98	525.40	--	653.40	1011.02
Model 2: Three-forward, three-backward	1048517	-9315.06	1473.56	948.16*	1589.56	1913.65
Model 3: Two-forward, two-backward	1048529	-9360.44	1564.31	1038.91*	1656.31	1913.35
Model 4: Two-forward, one-backward	1048538	-15651.10	14145.64	13620.24*	14219.64	14426.39
Model 5: One-forward, one-backward	1048547	-18252.15	19347.73	18822.33*	19403.73	19560.19
Model 6: Tau grades 6-7 vs. 7-8 equal	1048531	-8855.33	554.09	28.69	642.09	887.96
Model 7: Tau grades 6-7 vs. 8-9 equal	1048531	-8857.92	559.28	33.88*	647.28	893.14
Model 8: Tau grades 7-8 vs. 8-9 equal	1048531	-8847.36	538.16	12.76	626.16	872.02
Model 9: Tau grades 6-9 equal	1048551	-8866.09	575.61	21.52	623.61	757.72

Note: -LL = log likelihood; AIC = Akaike information criterion; BIC = Bayesian information criterion; DF = degrees of freedom; * = $p<0.05$; for ΔG^2, all models compared to Model 1 of respective condition (except Model 9, which is compared to Model 6).

Table 6. Transition parameters from parsimonious model for Fruit and Vegetable Consumption Stages.

		Stage in 7th Grade				
		PC	**C**	**PR**	**A**	**M**
	PC	0.32	0.31	0.16	0.10	0.11
		(-0.19)	*(+0.07)*	*(+0.01)*	*(0.00)*	*(+0.11)*
	C	0.10	0.28	0.36	0.17	0.10
		(-0.10)	*(-0.09)*	*(+0.07)*	*(+0.02)*	*(+0.10)*
Stage in 6th Grade	**PR**	0.07	0.21	0.43	0.15	0.14
		(-0.06)	*(-0.03)*	*(-0.01)*	*(-0.04)*	*(+0.14)*
	A	0.06	0.12	0.38	0.23	0.20
		(-0.10)	*(-0.07)*	*(+0.13)*	*(+0.17)*	*(-0.13)*
	M	0.05	0.12	0.24	0.17	0.42
		(-0.04)	*(-0.02)*	*(+0.01)*	*(+0.14)*	*(-0.10)*
				Stage in 8th Grade		
	PC	0.47	0.25	0.15	0.06	0.07
		(-0.04)	*(+0.01)*	*(+0.01)*	*(-0.05)*	*(+0.07)*
	C	0.16	0.38	0.29	0.06	0.11
		(-0.04)	*(+0.01)*	*(+0.01)*	*(-0.09)*	*(+0.11)*
Stage in 7th Grade	**PR**	0.07	0.19	0.50	0.07	0.17
		(-0.06)	*(-0.05)*	*(+0.06)*	*(-0.12)*	*(+0.17)*
	A	0.07	0.16	0.25	0.11	0.41
		(-0.09)	*(-0.03)*	*(-0.01)*	*(+0.06)*	*(+0.07)*
	M	0.02	0.06	0.15	0.05	0.72
		(-0.07)	*(-0.08)*	*(-0.07)*	*(+0.02)*	*(+0.20)*
				Stage in 9th Grade		
	PC	0.52	0.24	0.15	0.10	0.00
	C	0.20	0.37	0.28	0.15	0.00
Stage in 8th Grade	**PR**	0.12	0.24	0.45	0.19	0.00
	A	0.16	0.19	0.26	0.06	0.33
	M	0.09	0.14	0.22	0.03	0.52

Note: PC = Precontemplation; C= Contemplation; PR= Preparation; A = Action; M = Maintenance; values in parentheses represent the difference in the above parameter estimate from the comparison intervention.

Table 7. Model fit statistics for stage movement patterns within intervention condition for TV Viewing.

Stage Movement Pattern	**DF**	**-LL**	**G^2**	**ΔG^2**	**AIC**	**BIC**
Energy Balance Intervention						
Model 1: All free	1048511	-9679.97	678.47	--	806.47	1170.56
Model 2: Three-forward, three-backward	1048517	-11078.08	3474.68	2796.21*	3590.68	3920.64
Model 3: Two-forward, two-backward	1048529	-15418.45	12155.43	11476.96*	12247.43	12509.12
Model 4: Two-forward, one-backward	1048538	-17387.15	16092.82	15414.35*	16166.82	16377.31
Model 5: One-forward, one-backward	1048547	-20268.03	21854.57	21176.10*	21910.57	22069.86
Model 6: Tau grades 6-7 vs. 7-8 equal	1048531	-9709.80	738.13	59.66*	826.13	1076.44
Model 7: Tau grades 6-7 vs. 8-9 equal	1048531	-9766.17	850.86	172.39*	938.86	1189.18
Model 8: Tau grades 7-8 vs. 8-9 equal	1048531	-9744.07	806.66	128.19*	894.66	1144.97
Model 9: Tau grades 6-9 equal	1048551	-9791.72	901.96	163.83*	949.96	1086.49
Comparison Intervention						
Model 1: All free	1048511	-8360.30	575.85	--	703.85	1061.48
Model 2: Three-forward, three-backward	1048517	-9073.47	2002.20	1426.35*	2118.20	2442.29
Model 3: Two-forward, two-backward	1048529	-14365.62	12586.51	12010.66*	12678.51	12935.55
Model 4: Two-forward, one-backward	1048538	-16357.08	16569.42	15993.57*	16643.42	16850.17
Model 5: One-forward, one-backward	1048547	-18907.85	21670.96	21095.11*	21726.96	21883.42
Model 6: Tau grades 6-7 vs. 7-8 equal	1048531	-8382.56	620.38	44.53*	708.38	954.24
Model 7: Tau grades 6-7 vs. 8-9 equal	1048531	-8370.05	595.36	19.51	683.36	929.22
Model 8: Tau grades 7-8 vs. 8-9 equal	1048531	-8371.40	598.06	22.21	686.06	931.92
Model 9: Tau grades 6-9 equal	1048551	-8389.05	633.36	12.98	681.36	815.47

Note: -LL = log likelihood; AIC = Akaike information criterion; BIC = Bayesian information criterion; DF = degrees of freedom; * = $p<0.05$; for ΔG^2, all models compared to Model 1 of respective condition (except Model 9, which is compared to Model 6).

Table 8. Transition parameters from parsimonious model for TV Viewing stages.

		Energy Balance Condition				
		Stage at Month 12				
		PC	**C**	**PR**	**A**	**M**
	PC	0.46	0.14	0.08	0.23	0.09
		(-0.16)	*(+0.06)*	*(+0.04)*	*(-0.02)*	*(+0.09)*
	C	0.25	0.21	0.16	0.23	0.15
		(-0.11)	*(+0.00)*	*(+0.07)*	*(-0.11)*	*(+0.15)*
Stage at Baseline	**PR**	0.14	0.20	0.22	0.23	0.21
		(-0.12)	*(+0.05)*	*(+0.06)*	*(-0.20)*	*(+0.21)*
	A	0.12	0.08	0.07	0.34	0.39
		(-0.10)	*(+0.01)*	*(+0.02)*	*(0.00)*	*(+0.08)*
	M	0.06	0.04	0.05	0.24	0.61
		(-0.03)	*(+0.00)*	*(+0.02)*	*(+0.06)*	*(-0.04)*
		Stage at Month 24				
	PC	0.57	0.07	0.06	0.21	0.09
		(-0.04)	*(-0.02)*	*(+0.02)*	*(-0.05)*	*(+0.09)*
	C	0.31	0.23	0.11	0.23	0.12
		(-0.05)	*(+0.01)*	*(+0.02)*	*(-0.11)*	*(+0.12)*
Stage at Month 12	**PR**	0.13	0.19	0.23	0.24	0.21
		(-0.13)	*(+0.05)*	*(+0.07)*	*(-0.19)*	*(+0.21)*
	A	0.12	0.08	0.05	0.34	0.41
		(-0.10)	*(0.00)*	*(0.00)*	*(+0.01)*	*(+0.09)*
	M	0.07	0.02	0.03	0.11	0.76
		(-0.03)	*(-0.02)*	*(0.00)*	*(-0.06)*	*(+0.11)*
		Stage at Month 36				
	PC	0.62	0.08	0.04	0.26	0.00
	C	0.36	0.22	0.09	0.34	0.00
Stage at Month 24	**PR**	0.26	0.15	0.16	0.43	0.00
	A	0.22	0.07	0.06	0.33	0.32
	M	0.10	0.04	0.04	0.18	0.65

Note: PC = Precontemplation; C= Contemplation; PR= Preparation; A = Action; M = Maintenance; values in parentheses represent the difference in the above parameter estimate from the comparison intervention.

Table 9. Model fit results for stage movement across behavior in the energy balance intervention.

Comparison	**Pattern**	**DF**	**-LL**	**G^2**	**ΔG^2**	**AIC**	**BIC**
PA vs. FV	Model 1: All free	2097023	-18863.69	1270.97	--	1526.97	2343.88
	Model 2: Delta equal	2097027	-19020.96	1585.52	314.55*	1833.52	2624.89
	Model 3: Tau grades 6-7 equal	2097043	-18933.66	1410.92	139.95*	1626.92	2316.18
	Model 4: Tau grades 7-8 equal	2097043	-18910.20	1363.99	93.02*	1579.99	2269.26
	Model 5: Tau grades 8-9 equal	2097043	-18951.58	1446.75	175.78*	1662.75	2352.02
PA vs. TV	Model 1: All free	2097023	-18676.96	1269.98	--	1525.98	2342.88
	Model 2: Delta equal	2097027	-18958.17	1832.41	562.43*	2080.41	2871.78
	Model 3: Tau grades 6-7 equal	2097043	-18771.27	1458.60	188.62*	1674.60	2363.86
	Model 4: Tau grades 7-8 equal	2097043	-18794.69	1505.44	235.46*	1721.44	2410.70
	Model 5: Tau grades 8-9 equal	2097043	-18798.82	1513.71	243.73*	1729.71	2418.97
TV vs. FV	Model 1: All free	2097023	-19546.68	1357.92	--	1613.92	2430.83
	Model 2: Delta equal	2097027	-19901.83	2068.23	710.31*	2316.23	3107.60
	Model 3: Tau grades 6-7 equal	2097043	-19696.57	1657.72	299.80*	1873.72	2562.98
	Model 4: Tau grades 7-8 equal	2097043	-19723.21	1711.00	353.08*	1927.00	2616.26
	Model 5: Tau grades 8-9 equal	2097043	-19750.80	1766.18	408.26*	1982.18	2671.44

Note: -LL = log likelihood; AIC = Akaike information criterion; BIC = Bayesian information criterion; DF = degrees of freedom; * = $p<0{,}05$; for ΔG2, all models compared to Model 1 of respective condition (except Model 9, which is compared to Model 6).

Table 10. Model fit results for stage movement across behavior in the comparison intervention.

Comparison	**Pattern**	**DF**	**-LL**	**G^2**	**ΔG^2**	**AIC**	**BIC**
PA vs. FV	Model 1: All free	2097023	-16719.64	1049.93	--	*1305.93*	*2109.90*
	Model 2: Delta equal	2097027	-16869.55	1349.75	299.82*	*1597.75*	*2376.59*
	Model 3: Tau grades 6-7 equal	2097043	-16823.08	1256.81	206.88*	*1472.81*	*2151.15*
	Model 4: Tau grades 7-8 equal	2097043	-16807.22	1225.10	175.17*	*1441.10*	*2119.45*
	Model 5: Tau grades 8-9 equal	2097043	-16776.10	1162.85	112.92*	*1378.85*	*2057.20*
PA vs. TV	Model 1: All free	2097023	-16238.95	1100.39	--	*1356.39*	*2160.35*
	Model 2: Delta equal	2097027	-16588.23	1798.95	698.56*	*2046.95*	*2825.79*
	Model 3: Tau grades 6-7 equal	2097043	-16353.89	1330.27	229.88*	*1546.27*	*2224.61*
	Model 4: Tau grades 7-8 equal	2097043	-16388.83	1400.13	299.74*	*1616.13*	*2294.47*
	Model 5: Tau grades 8-9 equal	2097043	-16390.41	1403.29	302.90*	*1619.29*	*2297.64*
TV vs. FV	Model 1: All free	2097023	-17201.28	1101.26	--	*1357.26*	*2161.22*
	Model 2: Delta equal	2097027	-17490.24	1679.18	577.92*	*1927.18*	*2706.02*
	Model 3: Tau grades 6-7 equal	2097043	-17383.99	1466.67	365.41*	*1682.67*	*2361.01*
	Model 4: Tau grades 7-8 equal	2097043	-17434.64	1567.97	466.71*	*1783.97*	*2462.31*
	Model 5: Tau grades 8-9 equal	2097043	-17373.10	1444.89	343.63*	1660.89	2339.24

Note: -LL = log likelihood; AIC = Akaike information criterion; BIC = Bayesian information criterion; DF = degrees of freedom; * = $p<0,05$; for $\Delta G2$, all models compared to Model 1 of respective condition (except Model 9, which is compared to Model 6).

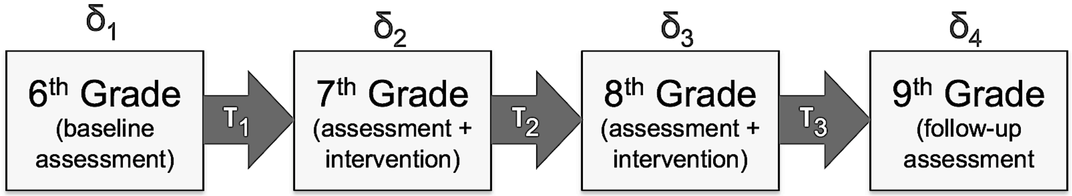

Figure 1. Outline of intervention time point and parameters estimated in the latent transition model. Note: δ_t = status (i.e. stage) prevalence at time *t*, τ_j = transition probability at transition *j*.

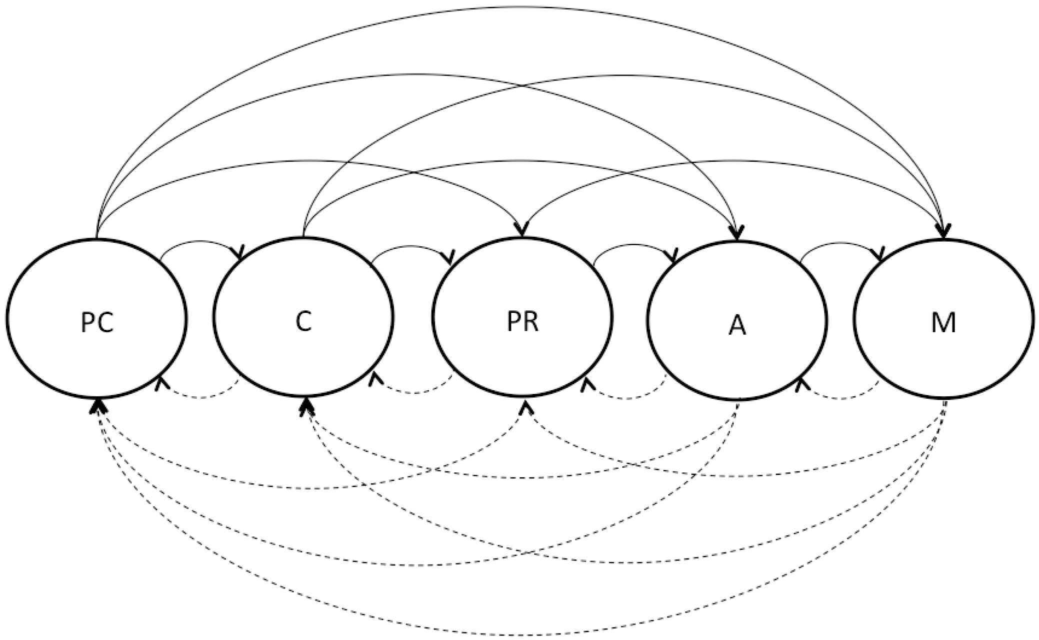

Figure 2. Stage movement model.
Note: PC = Precontemplation; C= Contemplation; PR= Preparation; A = Action; M = Maintenance; solid arrows indicate forward stage movement, dashed arrows indicate backwards stage movement; circles represent staying in that stage.

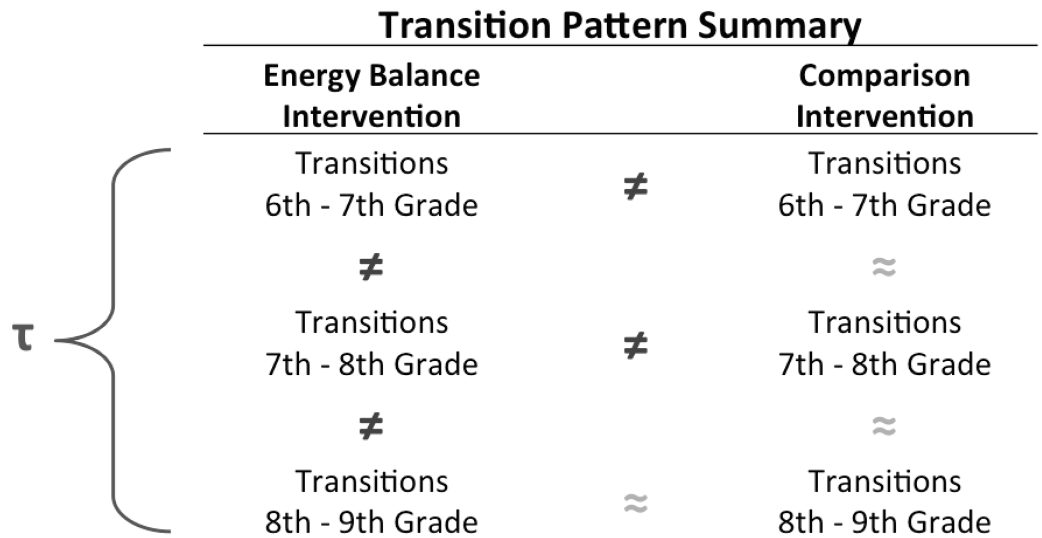

Figure 3. Summary of findings for transition matrices across grade transitions and intervention condition for physical activity, fruit and vegetable consumption, and TV viewing.
Note: τ (tau) matrices were equivalent (≈) or non-equivalent (≠) across time or intervention condition. These findings informed the optimized model for each behavior.

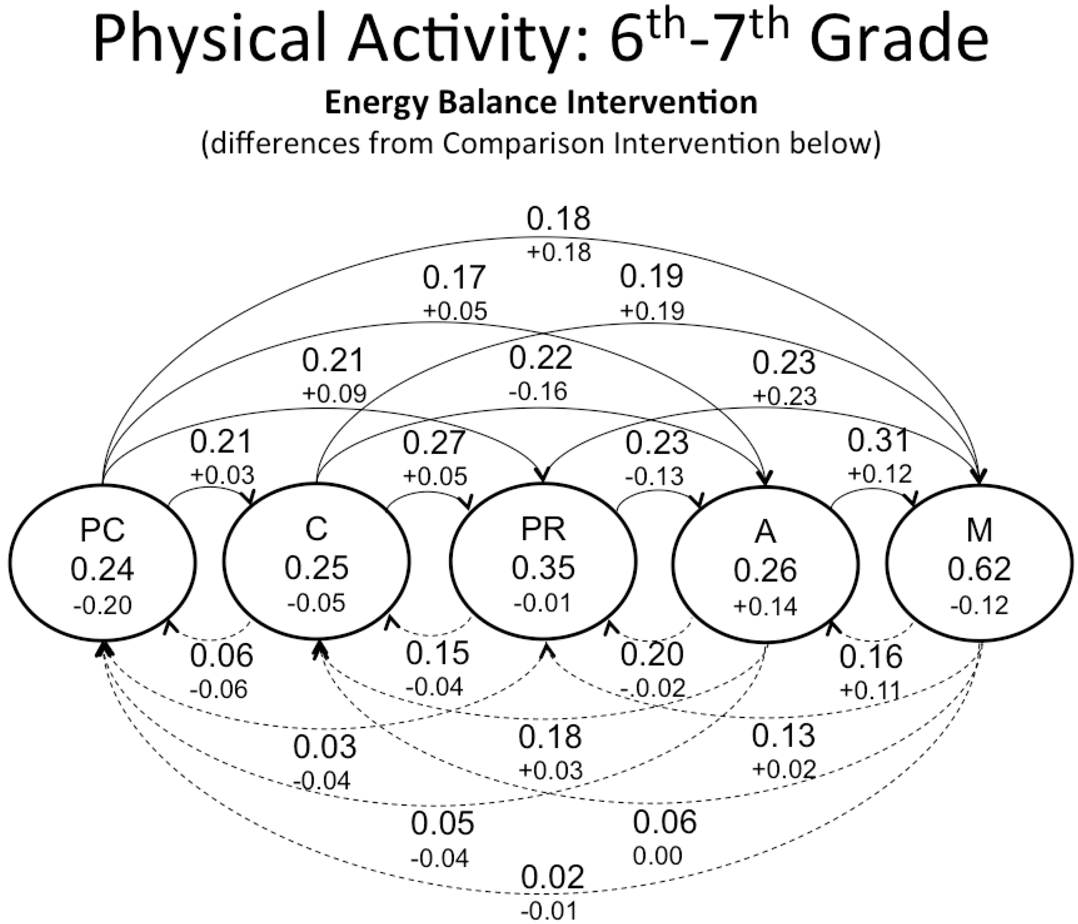

Figure 4. Physical activity stage movement from grades six to seven.
Note: PC = Precontemplation; C= Contemplation; PR= Preparation; A = Action; M = Maintenance; solid arrows indicate forward stage movement, dashed arrows indicate backwards stage movement; values inside circles represent staying in that stage; values placed below parameter estimates represent difference value from comparison intervention parameter estimate.

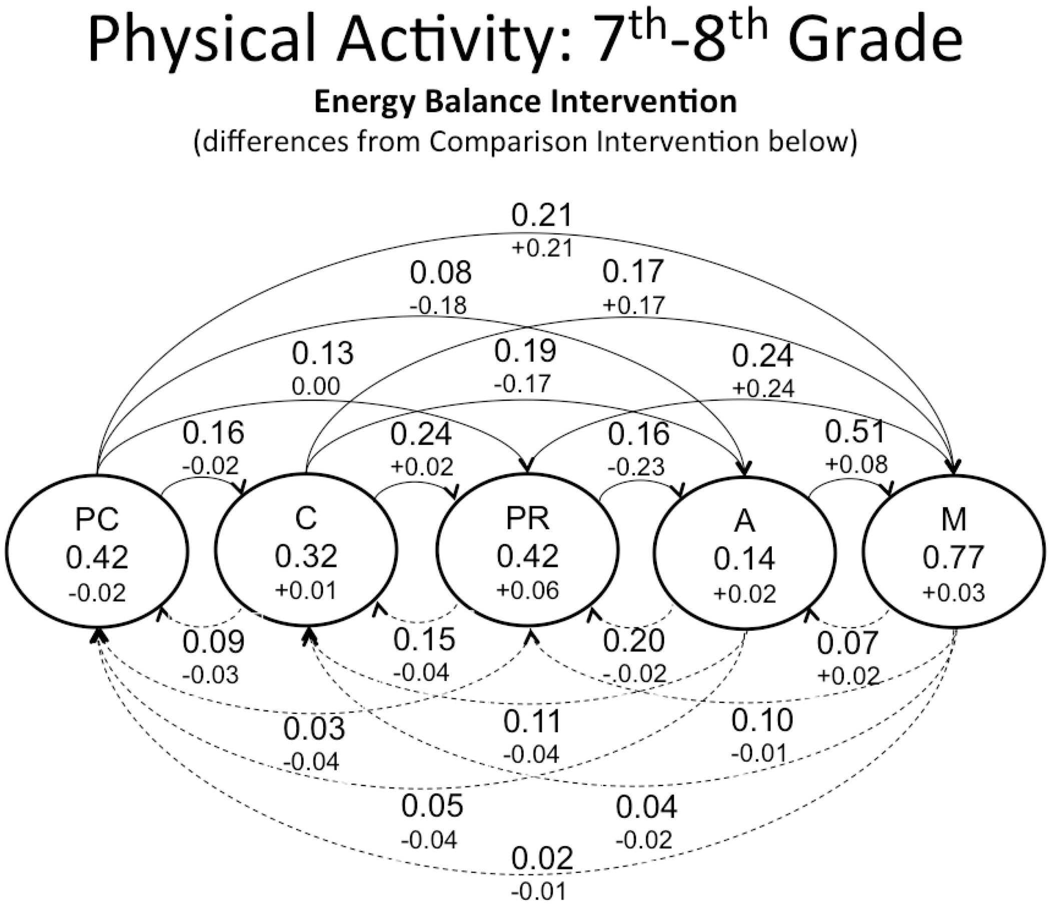

Figure 5. Physical activity stage movement from grades seven to eight.
Note: PC = Precontemplation; C= Contemplation; PR= Preparation; A = Action; M = Maintenance; solid arrows indicate forward stage movement, dashed arrows indicate backwards stage movement; values inside circles represent staying in that stage; values placed below parameter estimates represent difference value from comparison intervention parameter estimate.

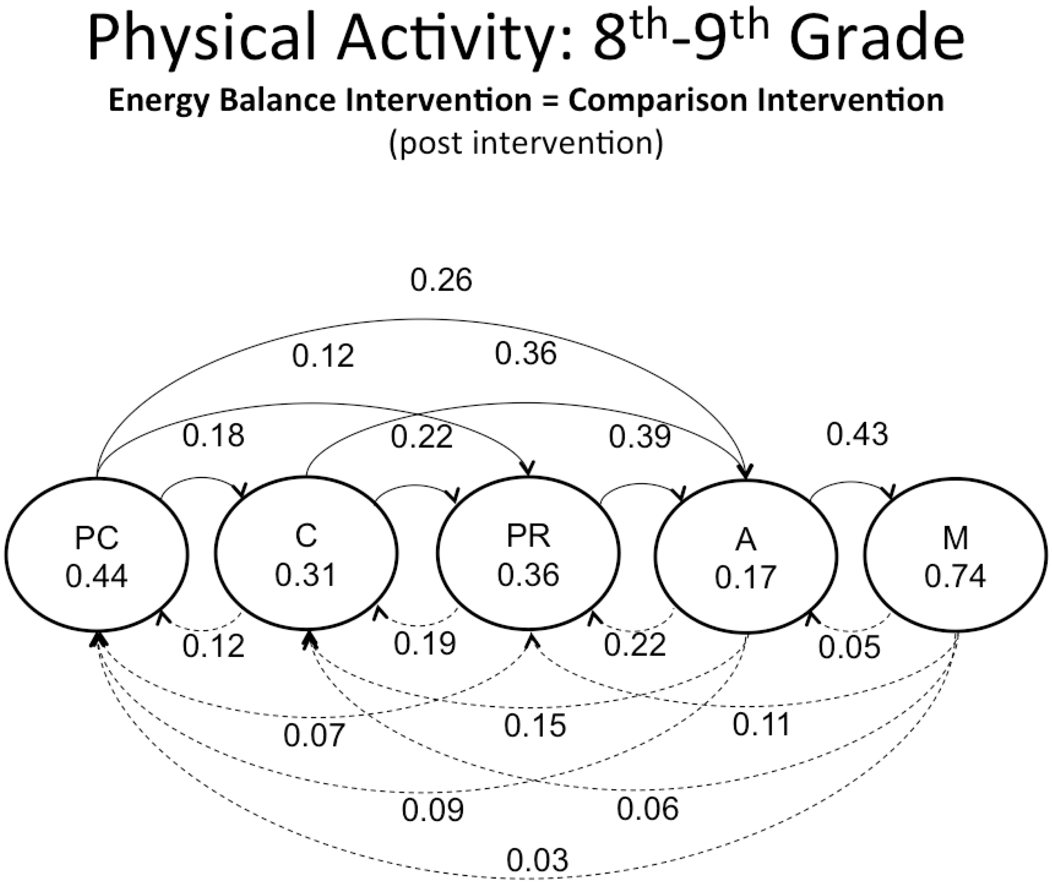

Figure 6. Physical activity stage movement from grades eight to nine.
Note: PC = Precontemplation; C= Contemplation; PR= Preparation; A = Action; M = Maintenance; solid arrows indicate forward stage movement, dashed arrows indicate backwards stage movement; values inside circles represent staying in that stage; values placed below parameter estimates represent difference value from comparison intervention parameter estimate.

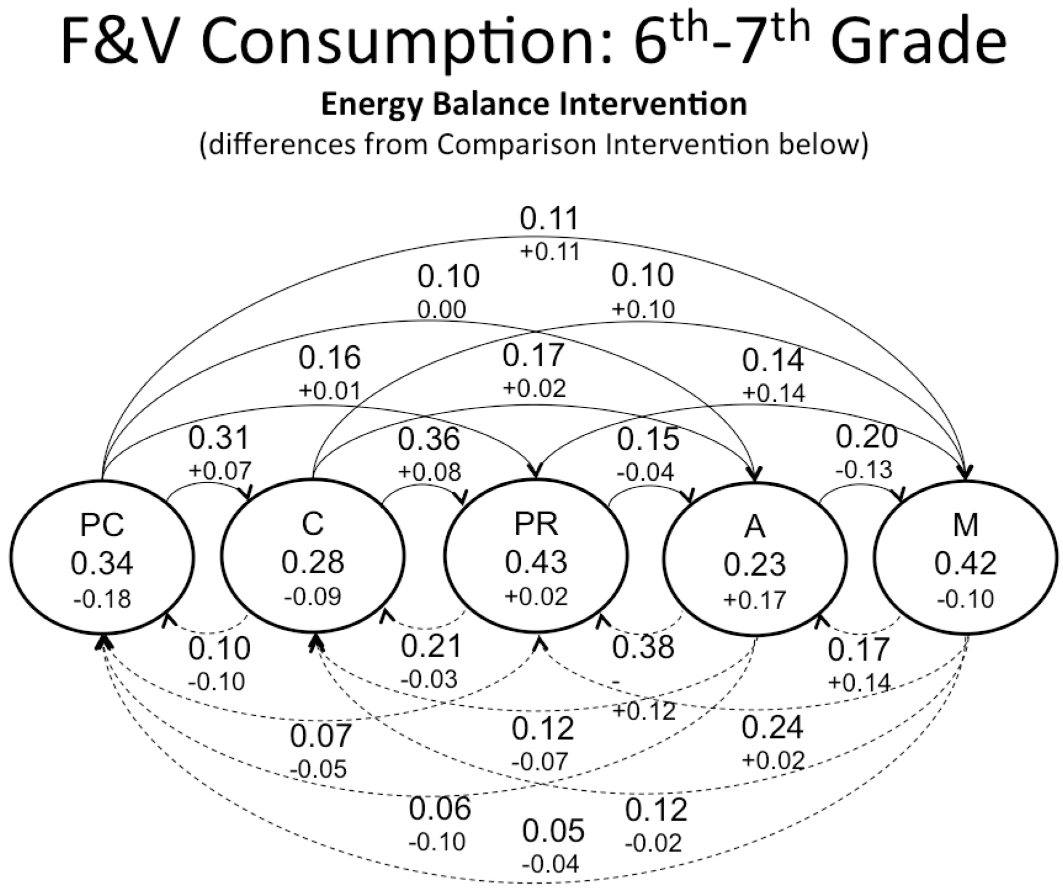

Figure 7. Fruit and vegetable consumption stage movement from grades six to seven. Note: PC = Precontemplation; C= Contemplation; PR= Preparation; A = Action; M = Maintenance; F&V = fruit and vegetable; solid arrows indicate forward stage movement, dashed arrows indicate backwards stage movement; values inside circles represent staying in that stage; values placed below parameter estimates represent difference value from comparison intervention parameter estimate.

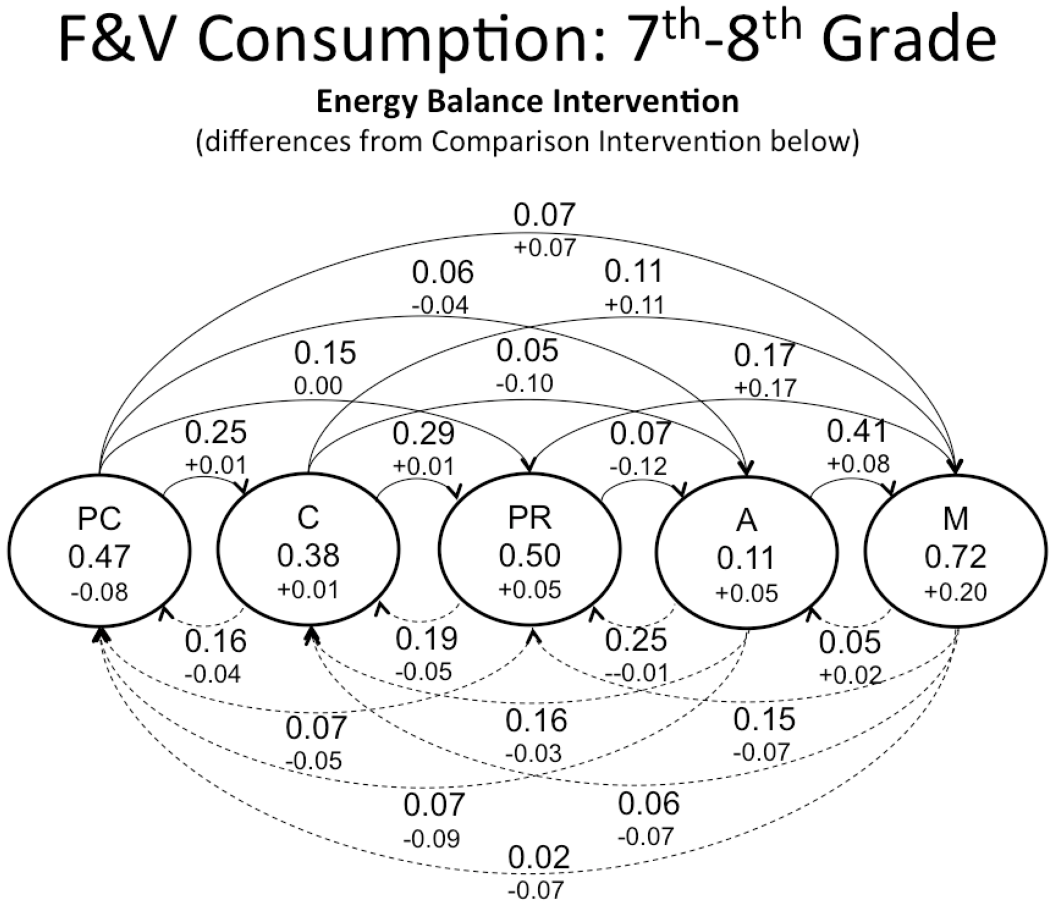

Figure 8. Fruit and vegetable consumption stage movement from grades seven to eight.

Note: PC = Precontemplation; C= Contemplation; PR= Preparation; A = Action; M = Maintenance; F&V = fruit and vegetable; solid arrows indicate forward stage movement, dashed arrows indicate backwards stage movement; values inside circles represent staying in that stage; values placed below parameter estimates represent difference value from comparison intervention parameter estimate.

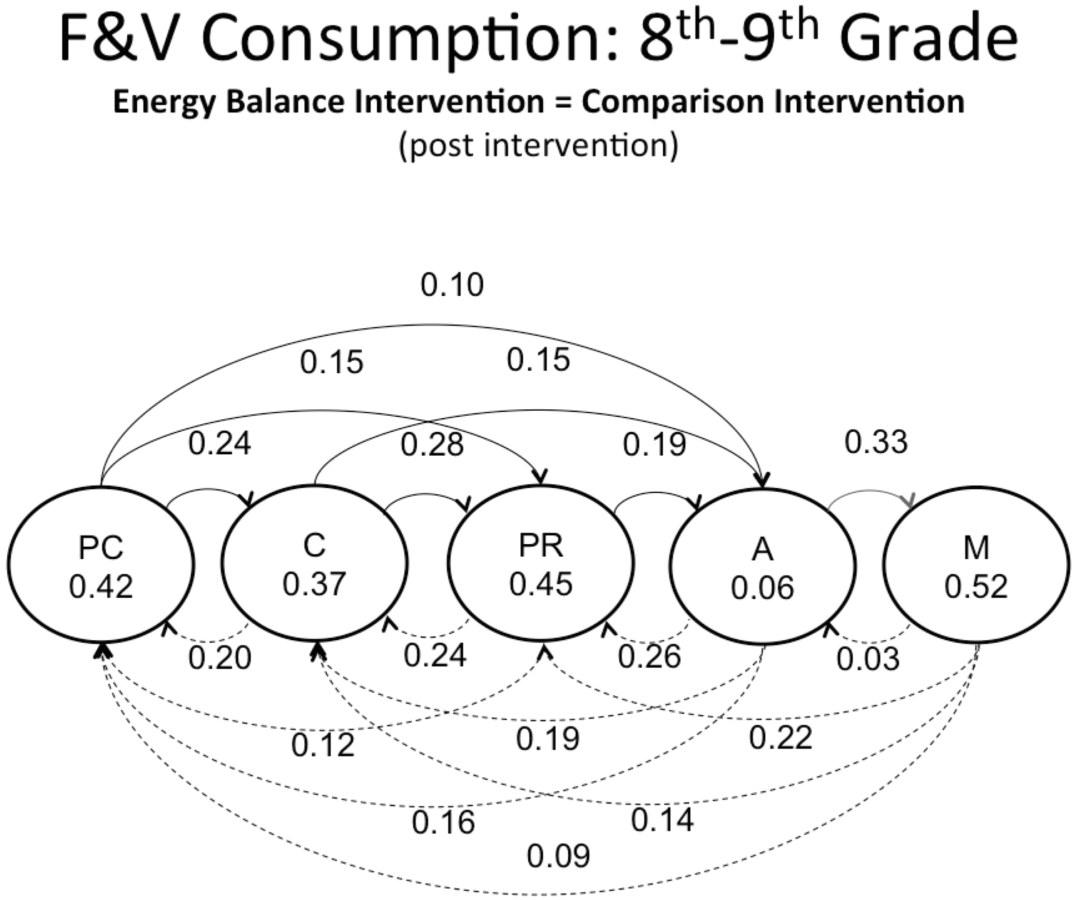

Figure 9. Fruit and vegetable consumption stage movement from grades eight to nine. Note: PC = Precontemplation; C= Contemplation; PR= Preparation; A = Action; M = Maintenance; F&V = fruit and vegetable; solid arrows indicate forward stage movement, dashed arrows indicate backwards stage movement; values inside circles represent staying in that stage; values placed below parameter estimates represent difference value from comparison intervention parameter estimate.

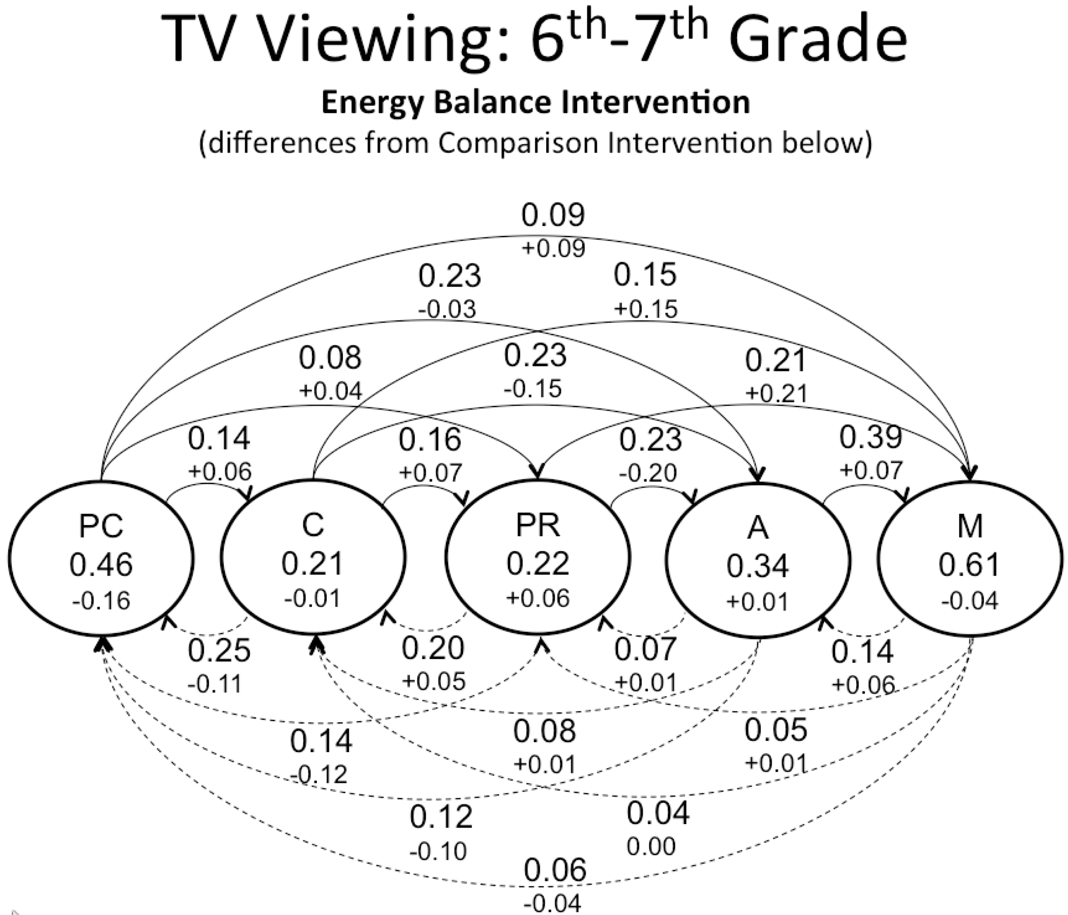

Figure 10. TV viewing stage movement from grades six to seven.
Note: PC = Precontemplation; C= Contemplation; PR= Preparation; A = Action; M = Maintenance; solid arrows indicate forward stage movement, dashed arrows indicate backwards stage movement; values inside circles represent staying in that stage; values placed below parameter estimates represent difference value from comparison intervention parameter estimate.

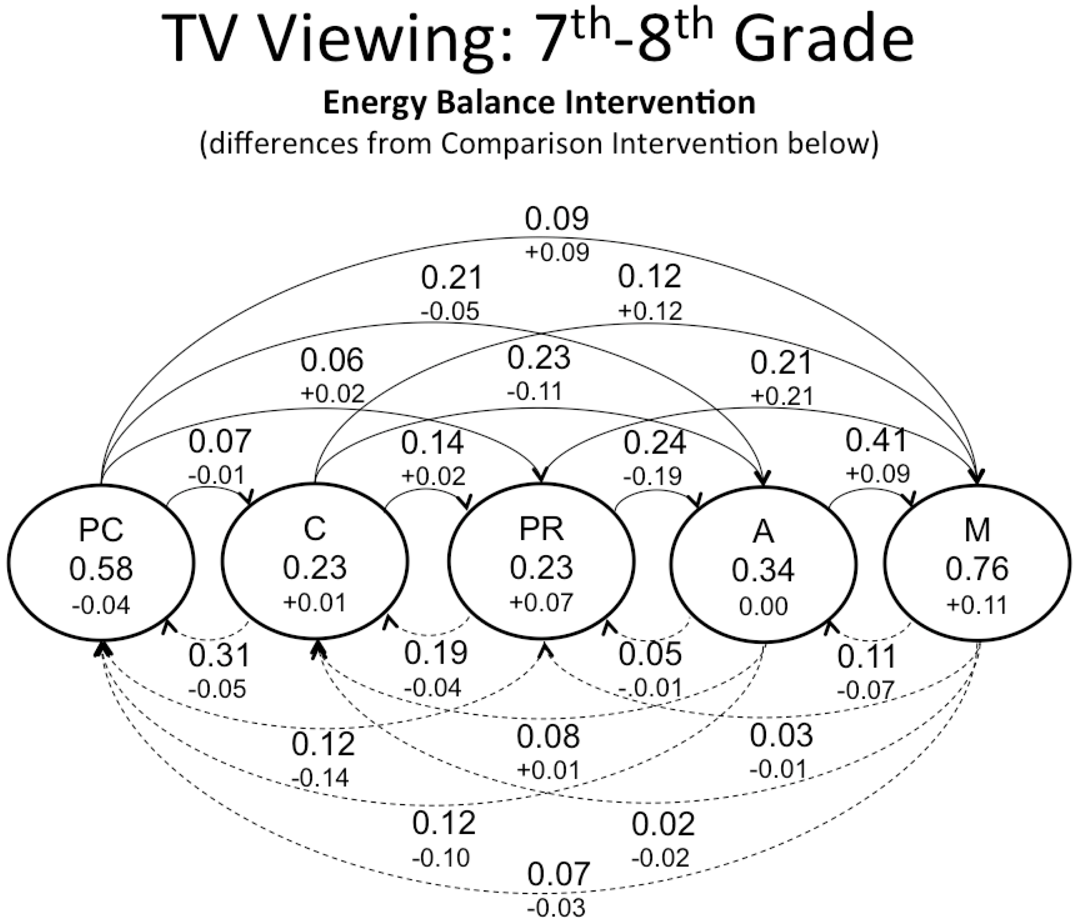

Figure 11. TV viewing stage movement from grades seven to eight.
Note: PC = Precontemplation; C= Contemplation; PR= Preparation; A = Action; M = Maintenance; solid arrows indicate forward stage movement, dashed arrows indicate backwards stage movement; values inside circles represent staying in that stage; values placed below parameter estimates represent difference value from comparison intervention parameter estimate.

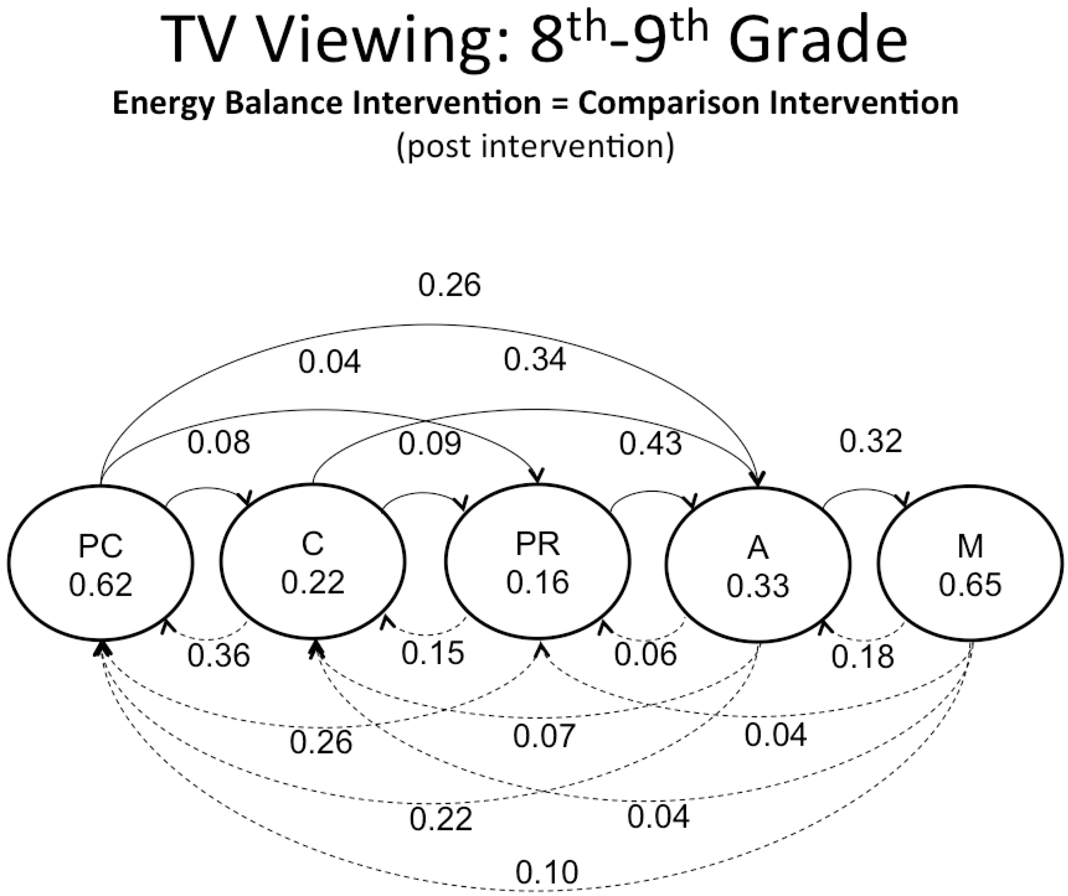

Figure 12. TV viewing stage movement from grades eight to nine.
Note: PC = Precontemplation; C= Contemplation; PR= Preparation; A = Action; M = Maintenance; solid arrows indicate forward stage movement, dashed arrows indicate backwards stage movement; values inside circles represent staying in that stage; values placed below parameter estimates represent difference value from comparison intervention parameter estimate.

MANUSCRIPT 2

Intervention effects on stage of change membership and transitions for middle school adolescent smoking and alcohol use acquisition

Intended Journal for Submission: Addictive Behaviors (not yet submitted)

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Abstract. The health impacts of smoking and alcohol abuse have been long established, with smoking representing one of the most preventable causes of disease and alcohol use the most popular psychoactive substance among adolescents. The current study evaluated Stage of Change progression in a large (N=4158) school-based, computer delivered, TTM-tailored multiple behavior intervention focusing on preventing acquisition of smoking and alcohol use in adolescents. Assessments began in sixth grade and continued yearly until eighth grade with a follow-up in ninth grade. Latent Transition Analysis was used to explore stage transitions across each behavior with a focus on answering three primary research questions: (1) What is the best fitting pattern of stage movement?; (2) Is the pattern of movement consistent over time?; and (3) Does intervention condition affect stage transitions? Major findings supported positive intervention effects for both the smoking and alcohol interventions and the comparison conditions, which focused on energy balance behaviors and provided no direct intervention on substance use behaviors. Substantial differences in stage membership and transitions across intervention conditions highlighted the process of smoking and alcohol use acquisition in middle school students in each intervention condition.

Intervention effects on stage of change membership and transitions for adolescent smoking and alcohol use acquisition

The health impacts of smoking have been long established, with nearly nine out of 10 smokers report starting before the age of 18 and most before the age of 27 (U.S. Department of Health and Human Services, 2014). In addition, adults who began drinking alcohol before the age of 14 are more likely to develop alcohol dependence or abuse later in life than people who began drinking after the age of 21 (Substance Abuse and Mental Health Services Administration, 2014). Cigarette smoking represents the largest preventable cause of death in the U.S. while alcoholic beverages represent the most common psychoactive substance used by young people in the U.S. (Johnston, O'Malley, Bachman, & Schulenberg, 2012). Accordingly, these behaviors are critical public health issues, which underline the importance of interventions to delay or prevent the onset of smoking and drinking in adolescents.

In an effort to prevent substance use, many researchers have turned to school-based interventions, albeit with mixed effectiveness. Successful and effective behavioral interventions may serve to prevent smoking uptake in adolescents, reduce daily smokering in young adulthood, increase quality-adjusted years of life, and reduce medical costs later in life (Wang & Michael, 2014). However, some studies have found no significant (Faggiano et al., 2010; Malmberg et al., 2015) or negative (Sloboda et al., 2009) treatment effects. A review of school-based interventions discussed successful components, such as booster sessions, normative feedback, programs delivered by mental health professionals, and programs with multiple levels of intervention (i.e. family, school, community), but also identified characteristics associated with lower intervention success, such as large scale programs and programs that focus only on smoking or only on alcohol (Nsimba & Amos, 2012).

A recent randomized school-based intervention reported findings from a Transtheoretical Model (TTM) computer-delivered, multiple behavior intervention in middle school students (Velicer et al., 2013). Briefly, the TTM has found that individuals vary in their general readiness to change their behavior, as well in their attitudes and beliefs about that change (Prochaska, 1983). The process of change is represented as a temporal sequence of behavioral and cognitive changes (Martin, Velicer, & Fava, 1996; Prochaska & Velicer, 1997; Velicer et al., 2000) and has been used to describe the process addictive behavior acquisition (Pallonen, Prochaska, Velicer, Prokhorov, & Smith, 1998). The school-based intervention developed by Velicer et al. (2013) consisted of two randomized TTM-tailored programs: one targeting smoking and alcohol use and a comparison intervention targeting at energy balance behaviors, including physical activity, diet, and TV viewing behaviors. Schools received either the substance use prevention program or the energy balance program, with each program serving as the control for the other. Main outcomes from this study indicated that students in the energy balance intervention effectively reduced smoking and alcohol acquisition relative to the substance use prevention condition, despite no direct treatment. Nevertheless, evidence for effectiveness of the intervention condition was also supported, as 7.5 % of students in the substance use intervention condition reported past 30-day smoking as compared to 8.6 % in nonstudy schools and 13.1 % of students reported alcohol use in the past 6 weeks compared to 15.9 % of students in nonstudy schools (Velicer at al., 2013). Thus, the intervention did indeed demonstrate positive effects but, contrary to the original hypothesis, effects in the energy balance condition appear to have exceeded those of the substance use prevention intervention.

In light of these findings, a detailed look at the underlying process of change for students in smoking and alcohol acquisition stages will inform future intervention studies aimed at preventing substance use. Stage progression is a dynamic process similar to a punctuated equilibrium model in which behavior can be characterized by long periods of stasis punctuated by periods of change. Latent transition analysis (LTA) is a longitudinal latent variable method that models discrete change in latent statuses and is particularly useful for stage-sequential models (Collins & Lanza, 2010; Velicer, Martin, & Collins, 1996). Thus, LTA can be used to identify categorical patterns of change among individuals by estimating the proportion of individuals in each stage as well as the probability of transitioning to another stage or to a substance user status and these movement patterns can be examined across both intervention conditions.

Hence, the current study aims to broaden the understanding of longitudinal patterns of TTM stage change by examining intervention effects on transitions for smoking and alcohol acquisition. It represents a more nuanced, follow-up study to main intervention findings from Velicer et al. (2013). Using LTA, the patterns of change across time, as well as differences in patterns across intervention condition, were examined separately for smoking and alcohol use acquisition. Three primary questions were assessed: (1) What is the best pattern of stage movement?; (2) Is the pattern of movement consistent over time?; and (3) Does intervention condition affect stage transitions?

Methods

Sample

Students (N=4158) were 47.8% female, 65.0% white, 15.6% Hispanic, 3.8% Black, 2.4% Asian, 2.2% American Indian/Alaskan Native, 0.5% Pacific Islander, and the remaining were unknown or a combination of ethnicities. Data were collected from middle schools across Rhode Island, which were matched on available school-level data (e.g. percent free lunch eligible, percent English as second language, percent attending college, racial/ethnic composition, smoking rate, and alcohol use rate) and randomized to one of two treatment groups. Students were eligible to participate if they were in sixth grade at the time of study and spoke English.

Intervention design

Half of the schools received a substance use prevention intervention and half received a comparison intervention that did not provide feedback on substance use behaviors but instead focused on promoting energy balance behaviors. The primary focus for the substance use intervention was to prevent smoking and alcohol acquisition or use by providing TTM-tailored cessation or prevention feedback. Since most of the participants were nonsmokers and nondrinkers, tailored feedback based on cluster profiles was generated using student scores on key TTM constructs, including Decisional Balance (i.e. the pros and cons) and Self-Efficacy (Johnson et al., 2006; Velicer, Redding, Anatchkova, Fava, & Prochaska, 2007). Participants in the comparison intervention received multiple health behavior feedback for physical activity, fruit and vegetable consumption, and TV viewing. Each intervention received a computerized assessment and intervention feedback using multimedia components (Redding et al., 1999; Velicer et al., 2013). Intervention material was disseminated during five 30-minute computerized TTM-tailored sessions with one in sixth grade, three in seventh grade, and one in eighth grade. A follow-up assessment was administered in ninth grade. For more detail regarding study design and outcomes, see Velicer et al. (2013).

Measures

The current study focused on answering the primary research questions with an emphasis on smoking and alcohol acquisition prevention. To determine current smoking and drinking status, students were first asked about their substance use behavior and this information was used to place each student into the appropriate acquisition Stage of Change.

Stage of change for smoking acquisition. Students who were current or former smokers at baseline (i.e. sixth grade) received a separate cessation intervention and were not included in the analyses for the current study. Students who responded as having never smoked or experimentally smoked, were considered non-smokers and received additional questions to determine their acquisition stage of change. If they were thinking about or planning to try smoking within the next 30 days they were classified in the acquisition-Preparation Stage (aPR), if they were thinking about or planning to try smoking within the next 6 months they were classified in the acquisition-Contemplation Stage (aC), and those who reported that they were not thinking of smoking in the next 6 months were classified in the acquisition-Precontemplation (aPC) stage (Plummer et al., 2001; Velicer et al., 2007). Students who were nonsmokers at baseline, but then became smokers during the study, were absorbed into the "ever-smoker" category and could not transition back to the acquisition stages. Students who were considered "ever-smokers" at baseline were provided separate feedback regarding cessation of smoking and are not included in the current study. Students who were not initially smokers, but became "ever-smokers" during the intervention, were also provided cessation information and were included in the "ever-smoker" category for the duration of the current study.

Stage of change for alcohol acquisition. Similar to the smoking algorithm, students who reported having consumed two or more drinks or had gotten very drunk at baseline (i.e. sixth grade) were categorized as "ever-drinkers" and were not included in the current study. Never drinkers and experimental drinkers received additional questions to determine their acquisition Stage of Change. If they were thinking about or planning to try drinking within the next 30 days they were classified in the acquisition-Preparation stage (aPR), if they were thinking about or planning to try drinking within the next 6 months they were classified in the acquisition-Contemplation Stage (aC), and those who reported that they were not thinking of drinking in the next 6 months were classified in the acquisition-Precontemplation (aPC) Stage. Students who were nondrinkers at baseline, but then tried drinking during the study, were absorbed into the "ever-drinker" category and could not transition back to the acquisition stages. Students who were considered "ever-drinker" at baseline were provided separate feedback regarding cessation of drinking and are not included in the current study. Students who were not initially drinkers, but became "ever-drinkers" during the intervention, were also provided cessation information and were included in the "ever-drinker" category for the duration of the current study.

Statistical Analyses

Statistical analyses were conducted using SAS version 9.3 with the SAS Macro for PROC LTA (PROC LCA & PROC LTA [Version 1.3.0], 2013). Missing data was handled by PROC LTA using the full-information maximum likelihood technique. Several indices of model fit were assessed. The goodness of fit index, G^2, is approximately distributed as a χ^2 and is used to compare nested models using log likelihood ratio G^2 difference tests (Collins & Lanza, 2010; Velicer et al., 1996). Due to known limitations of the chi-squared distribution with large sample sizes, the Akaike Information Criteria (Akaike, 1973) and the Bayesian Information Criteria (Schwarz, 1978) were also used to decide the best and most parsimonious model. However, many of these criteria tend to favor model complexity, thus parsimony will also be used to help guide the decision.

Due to the complexity and quantity of models in the current study, a brief note on the terminology is warranted. First, the authors acknowledge that the phrasing used in this study applies the term "equivalent" to mean "no evidence of statistical differences". The model comparison approach is used to test for significant changes in model fit when parameters are constrained to equality supports evidence for relatively equal parameter estimates. Second, three types of parameters are estimated in LTA: delta (the stage membership probability), tau (the transition probability, conditional on previous stage membership), and rho (the item-response probability for a given stage).

The study spanned a four-year period, from sixth to ninth grade, with annual assessments and a follow-up assessment administered without intervention material in ninth grade. The three transition periods are the main focus of this paper and are represented by the transitions from sixth to seventh, seventh to eighth, and eighth to ninth. Each LTA model estimates delta parameters (i.e. stage membership probabilities) for four possible categories across the four time points. These four categories are represented by the three acquisition stages of change (aPC, aC, aPR) and a fourth absorbing class in which participants become an "ever-smoker/drinker". Participants who enter the absorbing class have a zero probability of exiting, as they qualitatively leave the acquisition framework of substance use prevention. See Figure 1 for a visual depiction of the study flow and corresponding parameter estimates.

To characterize the overall pattern of behavior change, two primary types of model comparison tests were assessed. First, stage movement patterns examined model parameters for each intervention condition separately for both smoking and alcohol use. Second, intervention effects on transition parameters examined model parameters using multiple group models for smoking and alcohol separately with intervention as a grouping variable. Within each of these approaches, a series of nested models served to determine the best fitting model and demonstrate potential equivalence of parameters.

Intervention-specific stage movement patterns. To determine the best pattern of stage movement and whether the pattern was consistent across time, transition models were examined separately for each behavior within intervention group. Figure 2 depicts four possible movement patterns. In these figures, the probability of staying in a given stage is represented by a circle and the probability of transitioning is represented by either solid (for forward movement) or dashed (for backward movement) lines. First, a free transition model was estimated (Model 1) with no restrictions on delta or tau parameters. Then, constraints were placed on tau matrices to restrict forward and backward stage movement. These nested models were compared with the free model to determine the best fitting pattern. Model 2 restricted stage movement to two or less stages forward and/or backward, Model 3 restricted tau to two or less forward and/or one backward, and Model 4 restricted tau to one forward and/or one backward. The most restrictive model (Model 4) serves to inform whether behavior change occurs in a sequential pattern, while less restrictive models allow different patterns of stage progression and regression.

Next, to determine whether the best fitting stage movement model was consistent across time, models with successive tau matrices held equivalent were compared to the freely estimated model (Model 1). Model 5 held transition parameters from grades six to seven equivalent to grades seven to eight, Model 6 held parameters from grades seven eight equivalent to grades eight to nine, and Model 7 held parameters from grades six to seven equivalent to grades eight to nine. If parameters demonstrated equivalence, an additional model (Model 8) was tested that contained constraints across all three transitions to represent complete stability across all time points.

Intervention effects on transition parameters. To determine the equivalence of model parameters across intervention condition, a second series of nested model comparisons was conducted. First, a free transition multiple-group model (Model 1) was estimated to provide a comparison to more restricted models. Next, baseline delta parameters were constrained to equivalence across group (Model 2) to determine equality of baseline stage distributions. Then, each of the tau matrices for the three transition periods was held equivalent to identify differences in estimates across groups (Model 3 for the first transition matrix, Model 4 for the second transition, and Model 5 for the third transition). Finally, an optimized model (Model 6) was tested that integrate findings from the previous steps by holding transitions across time and across intervention condition equivalent to represent a final, reduced model. Thus, Model 6 represented the most parsimonious model of stage movement for each behavior.

Start values and parameter restrictions. Matrices containing start values and parameter restrictions are specified for model convergence and to facilitate model comparisons. Syntax for these matrices is available upon request. The rho matrices for all models are identical, with values fixed to invariance across time and all matrices present each stage as a single item indicator for each status. As noted before, all models contain an absorbing stage in which participants have a zero probability of transitioning out for every tau matrix.

Results

In sixth grade, there were 1,976 nonsmokers and 1,931 nondrinkers in the substance use prevention intervention and 2,184 nonsmokers and 2,140 nondrinkers in the comparison intervention. For both behaviors, the vast majority of students were in aPC in sixth grade. See Table 1 for model estimated stage prevalence across grades six through nine using a free transition model across each intervention group.

Smoking

Intervention specific stage movement patterns. Stage movement model fit results for each intervention condition are presented in Table 2. For the substance use intervention, significant ΔG^2 values revealed that the free transition model (Model 1) was favored over more restricted stage movement pattern models (Models 2-4). In addition, all models with successive tau matrices held equivalent (Models 5-7) revealed that G^2 fit, as well as AIC and BIC did not significantly worsen when compared to the free transition model, so a reduced model (Model 8) with all transitions equal over time was estimated to reduce complexity. This reduced model demonstrated non-significant ΔG^2 as well as low AIC and BIC values.

For the comparison intervention, significant ΔG^2 values also favored the free transition model (Model 1) over more restricted stage movement models (Models 2-4). Models with successive tau matrices held equivalent (Models 5-7) demonstrated that holding parameter estimates for the transition from grades six to seven equal to the transition from grades seven to eight (Model 5) as well as estimates for the transition from grades seven to eight equal to the transition from grades seven to eight equal to grades eight to nine (Model 7) both did not significantly worsen G^2 model fit and resulted in relatively low AIC and BIC values. However, the model comparing transitions from grades six to seven to transitions from grades eight to nine (Model 6) resulted in a significant decrease in model fit, suggesting that the pattern of movement probabilities during the transition from grades six to seven was not the same as the pattern of movement probabilities during the post-intervention follow-up.

Intervention effects on transition parameters. See Table 3 for fit indices for multiple-group models testing equivalence of parameters across intervention condition for smoking and alcohol use. See Figure 3 for a visual representation of smoking transition parameters across intervention.

When baseline delta parameters were held equivalent (Model 2) compared to the freely estimated model (Model 1), G^2 did not significantly change thereby indicating that constraining baseline stage membership probabilities across groups did not significantly worsen model fit. When tau parameters for the transitions from grades six to seven (Model 3) were held equivalent across groups, G^2 significantly changed, but did not for grades seven to eight (Model 4) or grades eight to nine (Model 5). This suggests initial intervention differences in transition parameters from grades six to seven but not for grades seven to nine.

These findings, in conjunction with the previous results for the best model of smoking stage movement patterns, informed a parsimonious model (Model 6). In this model, transition parameters within intervention were set to their best fitting model from the previous step (i.e. for the substance use intervention all transitions were equivalent across time and for the comparison intervention transitions for grades six to eight were equal, but transitions for grades eight to nine were different) and transition parameters across intervention condition were held equivalent for grades seven to nine. This model resulted in the greatest parsimony and the best comparative model fit.

Parameter estimates from the parsimonious model are presented in Figure 3, with difference values from the comparison intervention presented below the intervention estimates. aPC represented the most stable group, with highest probabilities of staying in aPC across all time points and both interventions. For grades six to seven, students in aPR in the intervention condition had a higher probability of transitioning into ever-smoker and a lower probability of transitioning into aPC relative to students in the comparison condition. In contrast, students in aC had a lower probability of transitioning into ever-smoker or aPR and a higher probability of transitioning back into aPC relative to students in the comparison group. No differences in parameters were observed from grades seven through nine. Overall, students in grades seven through nine were most likely to transition to ever-smoker if they had been in aC or aPR, but were more likely to transition to aPC from either of these groups than they were to become ever-smokers.

Alcohol Use

Intervention specific stage movement patterns. See Table 4 for model results of alcohol use stage movement pattern models specific to each intervention condition. As with smoking results, a free transition model (Model 1) was favored over more restricted transition models (Models 2-5) due to significant ΔG^2 values and lower AIC and BIC values in both intervention conditions.

In the substance use intervention, models with successive tau matrices held equivalent (Models 5-7) favored Model 7 such that transitions from grades six to seven were different from transitions from grades seven through nine. In the comparison intervention, all models holding transition parameters equivalent (Model

5-7) resulted in significant ΔG^2 and an increase the in AIC, thus the free transition model (Model 1) was favored. The BIC, however, favored Model 5.

Intervention effects on transition parameters. Refer to Table 4 for fit indices for multiple-group models testing equivalence of parameters across intervention condition for smoking and alcohol use. See Figure 4 for a visual representation of transition parameters across intervention for smoking and alcohol use, respectively.

When baseline delta parameters were held equivalent (Model 2), G^2 did not significantly change and the AIC and BIC values dropped relative to Model 1, indicating that constraining baseline stage membership probabilities across groups did not significantly worsen model fit. Next, after transition parameters for grades six to seven (Model 3) and grades seven to eight (Model 4) were held equivalent across intervention condition, G^2 significantly changed, but not across grades eight to nine (Model 5). This suggests intervention differences in transition parameter estimates between conditions from grades six to eight, but not from eight to nine.

These findings, in conjunction with the previous results for the best model of alcohol acquisition stage movement patterns, informed a parsimonious model (Model 6). In this model, transition parameters within intervention were set to their best fitting model (i.e. for the substance use intervention transitions for grades six to seven were different than grades seven to nine and for the comparison all transitions were different) and transition parameters across intervention condition were held equivalent for grades eight to nine. This model resulted in the greatest parsimony and the best comparative model fit.

Parameter estimates from the parsimonious model are presented in Figure 4, with difference values from the comparison intervention presented below the intervention estimates. Consistent with smoking stages, aPC represented the most stable group, with highest probabilities of staying in aPC across all time points and for both interventions, though these values decreased over time. From grades six to eight, students who had been in aC or aPR in the intervention condition had a higher probability of transitioning to ever-drinker and had a lower probability of transitioning into aPC than students in the comparison intervention. From grades seven to eight more students were found to stay in aPR. Finally, parameter estimates were found to be equivalent across intervention condition for the transition from grades eight to nine. Overall, students in in the intervention were more likely to transition to ever-drinker and less likely to transition to aPC than students in the comparison condition, but the probabilities of transitioning backwards (i.e. toward aPC) tended to be higher than it was to transition into ever-drinker.

Discussion

Transition models provide insight beyond cross sectional stage membership distributions to help shed light on how adolescents are changing in their smoking and alcohol use acquisition over time. In sixth grade, nonsmoking/nondrinking students had a 98-99% probability of reporting no plans to try smoking or drinking, yet by the end of the study had a 11% and 9% probability of membership in the substance use and comparison interventions for becoming ever-smokers, and a 19% and 13% probability of becoming ever-drinkers in the substance use and comparison interventions, respectively. Probability of movement directly from aPC to ever-drinker/smoker was low (<6%), revealing that most transitions into the ever-smoker/drinker status were from aC or aPR and, counter to predictions, higher probabilities were found in the intervention group. Though the comparison intervention outperformed the substance use intervention, it is important to consider that both interventions resulted in decreased rates of ever-smoking and ever-drinking compared to rates from non-participating Rhode Island schools (Velicer et al., 2013). Current rates for ever-smoking in middle schools, as defined by having ever tried cigarettes, even one or two puffs, for the state of Rhode Island are estimated at 24% and at 31% nationally (Youth Risk Behavior Surveillance, 2013). Current rates for ever-drinking in middle schools, as defined by having ever had at least one drink of alcohol at least one day in their life are estimated at 48% for the State of Rhode Island and 56% nationally (Youth Risk Behavior Surveillance, 2013). The model estimated probabilities in the current study were based on less stringent definitions of ever-smoking and ever-drinking, thus these low prevalence rates lend support for effectiveness of preventing addictive behavior acquisition in both interventions.

Patterns of stage movement were similar across smoking and alcohol use. For both behaviors, and for both intervention conditions, the best pattern of stage movement was one in which no restrictions were placed on stage progression or regression. Thus, although the probability of transition from aPC to ever-smoker/drinker was very low, models that constrained this transition significantly worsened model fit.

In the intervention condition, smoking stage transitions were found to be equivalent across grades six through nine but were only found to be equivalent across grades six through eight for the alcohol stage transitions. In the comparison condition, smoking stage transitions were found to be equivalent across grades six through eight and were found to be nonequivalent across all grades for alcohol stage transitions. Comparatively, students had similar probabilities of transitioning into ever-drinker, but were less likely to transition backwards toward aPC for alcohol use than for smoking and membership in aPC remained high for smoking and decreased slightly for alcohol use. These findings may be due in part to alcohol use being more common than smoking (Johnston et al., 2012) and the declining popularity of cigarette use (Kann et al., 2014) in adolescents, leading students to be more tempted to try drinking than to try smoking.

Models comparing stage transitions across intervention condition found similar patterns for smoking and alcohol use. Both behaviors exhibited relatively equivalent stage distributions in sixth grade across intervention condition. This finding was expected, since students were randomized into each condition they should demonstrate similar baseline stage distributions. For smoking, transitions from grades six to seven were not equivalent across intervention group, but were for grades seven through nine, suggesting initial intervention differences that subsided after the transition from six to seventh grade. For alcohol use, transitions from grades six through eight were not equivalent across groups, but were equivalent for grades eight to nine, suggesting differences that subsided after the end of the intervention in eighth grade.

In addition to potential effects from differences in popularity and temptation to use alcohol over cigarettes in adolescents, stage transitions may be influenced by the content of each intervention differently. Specifically, both interventions resulted in prevention of acquisition of smoking and alcohol use by ninth grade, but the comparison condition outperformed the substance use intervention, despite no direct treatment for substance use behaviors. One potential reason for this may lie in the intervention material itself: the comparison condition consisted of a "positive intervention" focused on promoting physical activity, fruit and vegetable consumption, and reduced TV viewing. Thus, the aspects of this intervention were dedicated to promote wellness, healthy behavior, and had messages targeting positive outcomes. The substance use intervention, in contrast, focused on preventing or reducing negative behaviors like smoking and drinking alcohol. Thus, one of the most intriguing findings from this study lies in the possibility that the comparison condition may have indirectly done a better job at preventing smoking and alcohol use acquisition. Effects from this focus on positive health behaviors may have influenced smoking and alcohol use acquisition even though they were never given feedback on these behaviors. Future studies should examine the notion of whether intervening on energy behaviors have transfer effects or indirect protective effects on other types of "negative" behaviors like substance use prevention.

One noteworthy limitation to this study was the lack of a true no-treatment control group that could provide an indication of normative or natural change in adolescents. Without an index of natural change in smoking and drinking behavior in relation to acquisition stages as students move from sixth to ninth grade, it is hard to determine the extent of the intervention effects, especially given that both interventions appeared to prevent smoking and alcohol use acquisition when rates of past 30 day smoking and past 6 week drinking were compared to nonstudy schools. Consideration of the decision against including a no-treatment control is described in the original study, which highlights the choice in a two-treatment control comparison trial as more cost effective, maximized school participation, and met curriculum demands of participating schools (Velicer et al., 2013). The current study also did not take into account the nesting of students within schools. Future studies could incorporate school-level information into the analyses to test for school-specific effects. In addition, the approach used in this study modeled stage in such that it was characterized as a manifest variable indicated by a single item (i.e. the result of the staging algorithm). Consequently, the model does not incorporate measurement error. Future studies may consider using multiple measures of stage of change to incorporate measurement error and represent stage as a truly “latent” variable.

Another limitation of this study is the lack in a good index of model fit to aid in interpretation of model comparison results. The fit indices currently available for most statistical programs (i.e. G^2, AIC, BIC) that conduct LTA have been criticized for their lack of robustness and unrealistic assumptions (Dziak, Coffman, Lanza, & Li, 2012). It is largely unknown how adequate these indices are in complex LTA models with large degrees of freedom, such as the models tested in this paper (Lanza & Bray, 2010).

Conclusion

Despite the fact that most students from sixth to ninth grade report not being interested in trying smoking or drinking, many indeed go on to begin smoking and drinking in high school. Findings from this study demonstrated that students in aPC were less likely to ever try smoking or drinking than students in aC or aPR and that both interventions resulted in generally more backwards movement toward aPC (i.e. prevention) than movement toward ever-smoking/drinking (i.e. substance use acquisition). Contrary to the original hypothesis, the comparison intervention resulted in fewer students transitioning to trying smoking or drinking than the substance use intervention. Both interventions, however, appear to have provided protective effects on smoking and alcohol use acquisition in adolescents.

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Table 1. Model estimated stage membership probabilities for substance use behaviors.

Intervention	Time Point	aPC	aC	aPR	Ever-Smoker/ Drinker
Substance Use Prevention Intervention					
Smoking	6th grade	0.99	<0.01	0.01	*0.00
	7th grade	0.94	0.01	0.01	0.03
	8th grade	0.90	0.01	0.01	0.07
	9th grade	0.87	0.01	0.01	0.11
Alcohol Use	6th grade	0.98	0.01	0.01	*0.00
	7th grade	0.91	0.02	0.01	0.06
	8th grade	0.79	0.05	0.04	0.12
	9th grade	0.71	0.06	0.04	0.19
Comparison Intervention					
Smoking	6th grade	0.99	<0.01	0.01	*0.00
	7th grade	0.97	<0.01	0.01	0.02
	8th grade	0.92	0.01	0.01	0.05
	9th grade	0.89	0.01	0.01	0.09
Alcohol Use	6th grade	0.98	0.01	0.01	*0.00
	7th grade	0.94	0.03	0.01	0.03
	8th grade	0.88	0.03	0.03	0.06
	9th grade	0.77	0.06	0.04	0.13

Note: aPC = acquisition Precontemplation; aC= acquisition Contemplation; PR= acquisition Preparation; model estimated delta parameters from free transition multiple group model; * = membership probability fixed to zero.

Table 2. Model fit statistics for smoking acquisition stage movement patterns within intervention condition.

Stage Movement Pattern	**DF**	**-LL**	**AIC**	**BIC**	**G^2**	**ΔG^2**
Substance Use Prevention Intervention						
Model 1: All free	65505	-1481.29	87.23	254.86	27.23	--
Model 2: Two-forward, two-backward	65508	-2256.45	1631.53	1782.40	1577.53	1550.30*
Model 3: Two-forward, one-backward	65511	-2449.20	2011.04	2145.15	1963.04	1935.81*
Model 4: One-forward, one-backward	65517	-3181.12	3462.87	3563.46	3426.87	3399.64*
Model 5: Tau grades 6-7 vs. 7-8 equal	65514	-1485.89	78.42	195.77	36.42	9.19
Model 6: Tau grades 6-7 vs. 8-9 equal	65514	-1485.33	77.29	194.63	35.29	8.06
Model 7: Tau grades 7-8 vs. 8-9 equal	65514	-1483.60	73.83	191.18	31.83	4.60
Model 8: Tau grades 6-9 equal	65523	-1488.63	65.90	132.95	41.90	5.48
Comparison Intervention						
Model 1: All free	65505	-1206.50	86.45	257.12	26.45	--
Model 2: Two-forward, two-backward	65508	-1750.50	1168.45	1322.05	1114.45	1088.00*
Model 3: Two-forward, one-backward	65511	-1947.07	1555.59	1692.12	1507.59	1481.14*
Model 4: One-forward, one-backward	65517	-2455.81	2561.05	2663.45	2525.05	2498.60*
Model 5: Tau grades 6-7 vs. 7-8 equal	65514	-1212.88	81.21	200.67	39.21	12.76
Model 6: Tau grades 6-7 vs. 8-9 equal	65514	-1218.89	93.22	212.69	51.22	24.77*
Model 7: Tau grades 7-8 vs. 8-9 equal	65514	-1213.66	82.77	202.24	40.77	14.32

Note: -LL = log likelihood; AIC = Akaike information criterion; BIC = Bayesian information criterion; DF = degrees of freedom; all models compared to Model 1 of respective condition (except Model 8, which is compared to Model 5); * = $p<0.05$.

Table 3. Model fit statistics for smoking and alcohol stage movement patterns across intervention condition.

Model: Constraints	**DF**	**-LL**	**AIC**	**BIC**	**G^2**	**ΔG^2**
Smoking						
Model 1: All free	131011	-2687.8	173.67	553.64	53.67	--
Model 2: Delta equal at baseline	131014	-2690.16	172.4	533.37	58.4	4.73
Model 3: Tau grades 6-7 equal	131023	-2706.93	187.94	491.91	91.94	33.54*
Model 4: Tau grades 7-8 equal	131023	-2696.78	167.64	471.61	71.64	13.24
Model 5: Tau grades 8-9 equal	131023	-2691.37	156.81	460.79	60.81	2.41
Model 6: Parsimonious	131050	-2709.67	139.42	272.41	97.421	39.02
Alcohol Use						
Model 1: All free	131011	-4801.34	243.88	622.57	123.88	--
Model 2: Delta equal at baseline	131014	-4802.61	240.42	600.19	126.42	2.54
Model 3: Tau grades 6-7 equal	131023	-4816.55	250.31	553.27	154.31	27.89*
Model 4: Tau grades 7-8 equal	131023	-4811.74	240.68	543.64	144.68	18.26*
Model 5: Tau grades 8-9 equal	131023	-4806.3	229.8	532.76	133.8	7.38
Model 6: Parsimonious	131032	-4814.12	227.44	473.59	149.44	23.02

Note: -LL = log likelihood; AIC = Akaike information criterion; BIC = Bayesian information criterion; DF = degrees of freedom; all models compared to Model 1 of respective condition (except Model 6, which is compared to Model 2) ; * = $p<0.05$.

Table 4. Model fit statistics for alcohol use acquisition stage movement patterns within intervention condition.

Stage Movement Pattern	**DF**	**-LL**	**AIC**	**BIC**	**G^2**	**ΔG^2**
Substance Use Prevention Intervention						
Model 1: All free	65505	-1481.29	87.23	254.86	27.23	--
Model 2: Two-forward, two-backward	65508	-2256.45	1631.53	1782.40	1577.53	1550.30*
Model 3: Two-forward, one-backward	65511	-2449.20	2011.04	2145.15	1963.04	1935.81*
Model 4: One-forward, one-backward	65514	-1483.60	73.83	191.18	31.83	4.60
Model 5: Tau grades 6-7 vs. 7-8 equal	65514	-1485.89	78.42	195.77	36.42	9.19
Model 6: Tau grades 6-7 vs. 8-9 equal	65514	-1485.33	77.29	194.63	35.29	8.06
Model 7: Tau grades 7-8 vs. 8-9 equal	65514	-1483.60	73.83	191.18	31.83	4.60
Model 8: Tau grades 6-9 equal	65523	-1488.63	65.90	132.95	41.90	5.48
Energy Balance Intervention						
Model 1: All free	65505	-1206.50	86.45	257.12	26.45	--
Model 2: Two-forward, two-backward	65508	-1750.50	1168.45	1322.05	1114.45	1088.00*
Model 3: Two-forward, one-backward	65511	-1947.07	1555.59	1692.12	1507.59	1481.14*
Model 4: One-forward, one-backward	65517	-2455.81	2561.05	2663.45	2525.05	2498.60*
Model 5: Tau grades 6-7 vs. 7-8 equal	65514	-1212.88	81.21	200.67	39.21	12.76
Model 6: Tau grades 6-7 vs. 8-9 equal	65514	-1218.89	93.22	212.69	51.22	24.77*
Model 7: Tau grades 7-8 vs. 8-9 equal	65514	-1213.66	82.77	202.24	40.77	14.32

Note: -LL = log likelihood; AIC = Akaike information criterion; BIC = Bayesian information criterion; DF = degrees of freedom; all models compared to Model 1 of respective condition (except Model 8, which is compared to Model 5); * = $p<0.05$.

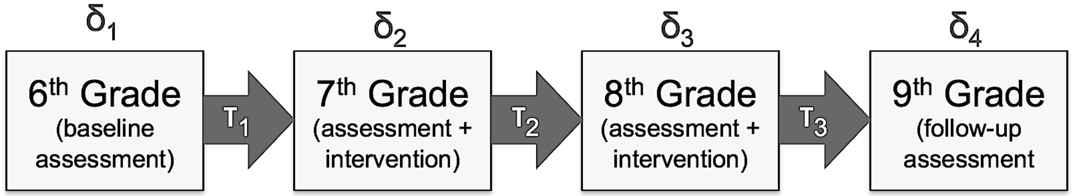

Figure 1. Outline of intervention time point and parameters estimated in the latent transition model. Note: δ_t = status (i.e. stage) prevalence at time *t*, τ_j = transition probability at transition *j*.

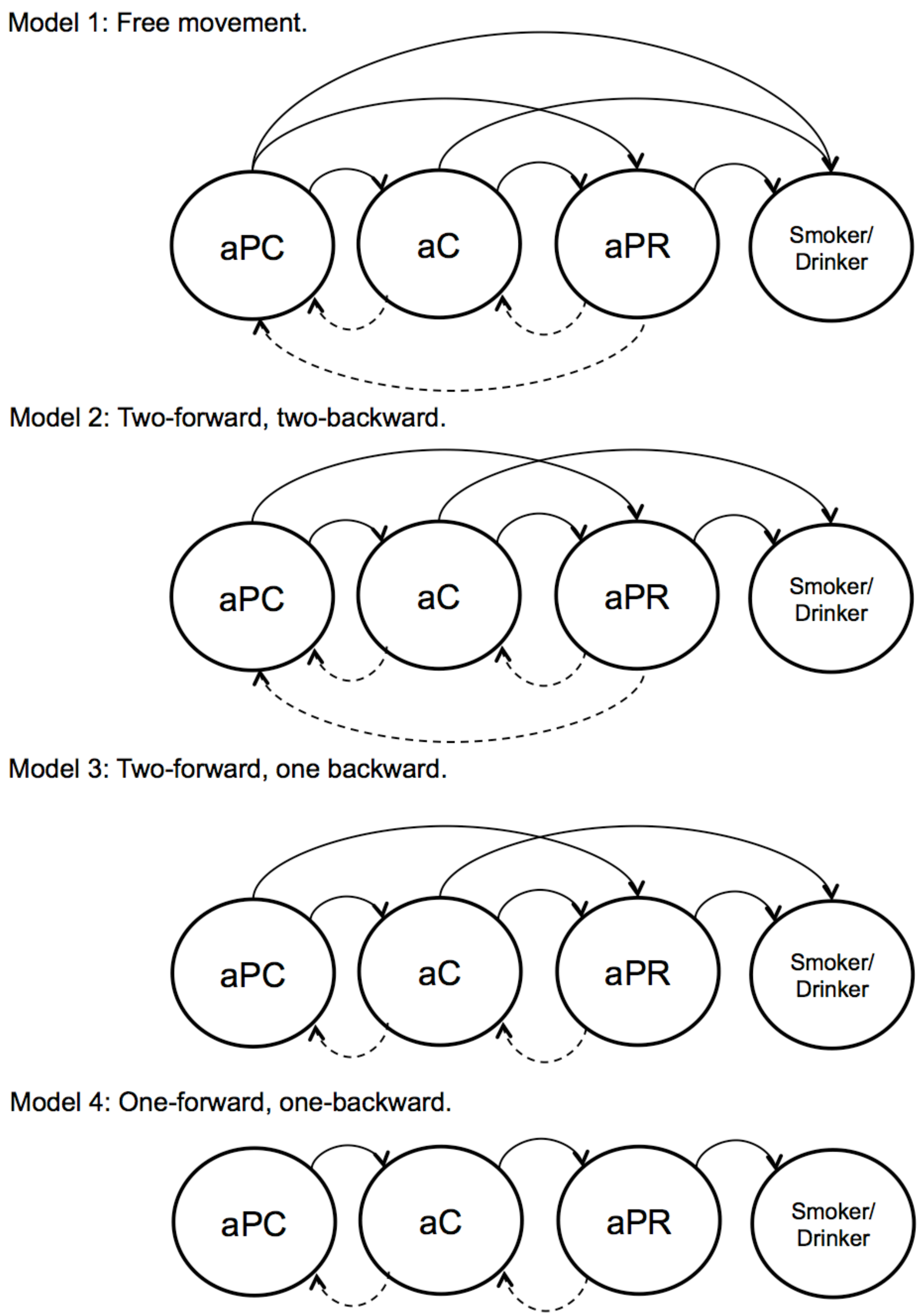

Figure 2. Movement pattern models.
Note: aPC = acquisition Precontemplation; C= acquisition Contemplation; PR= acquisition Preparation; solid arrows indicate forward stage movement, dashed arrows indicate backwards stage movement.

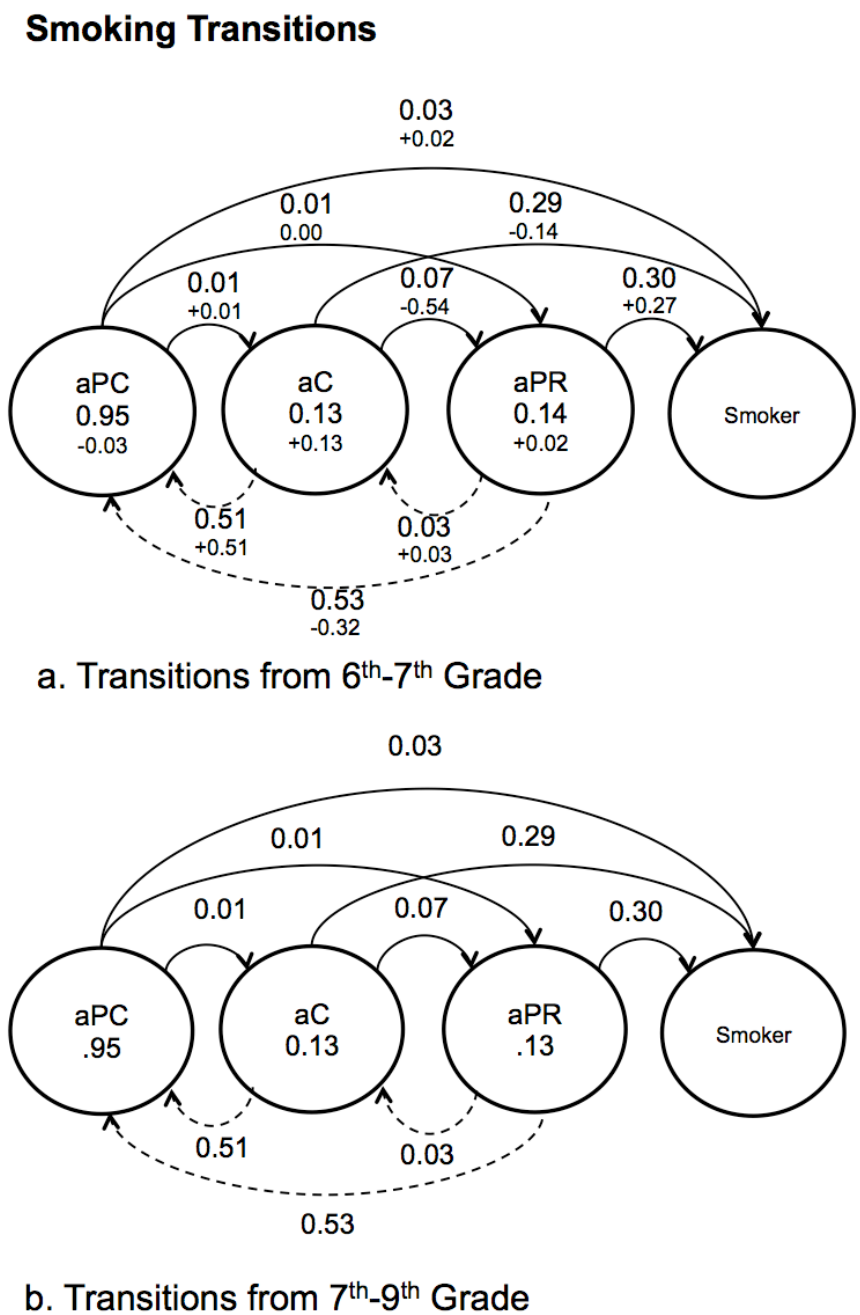

Figure 3. Transition probabilities in the substance use intervention for smoking. Note: aPC = acquisition Precontemplation; C= acquisition Contemplation; PR= acquisition Preparation; solid arrows indicate forward stage movement, dashed arrows indicate backwards stage movement; differences from comparison condition are presented below parameter estimates.

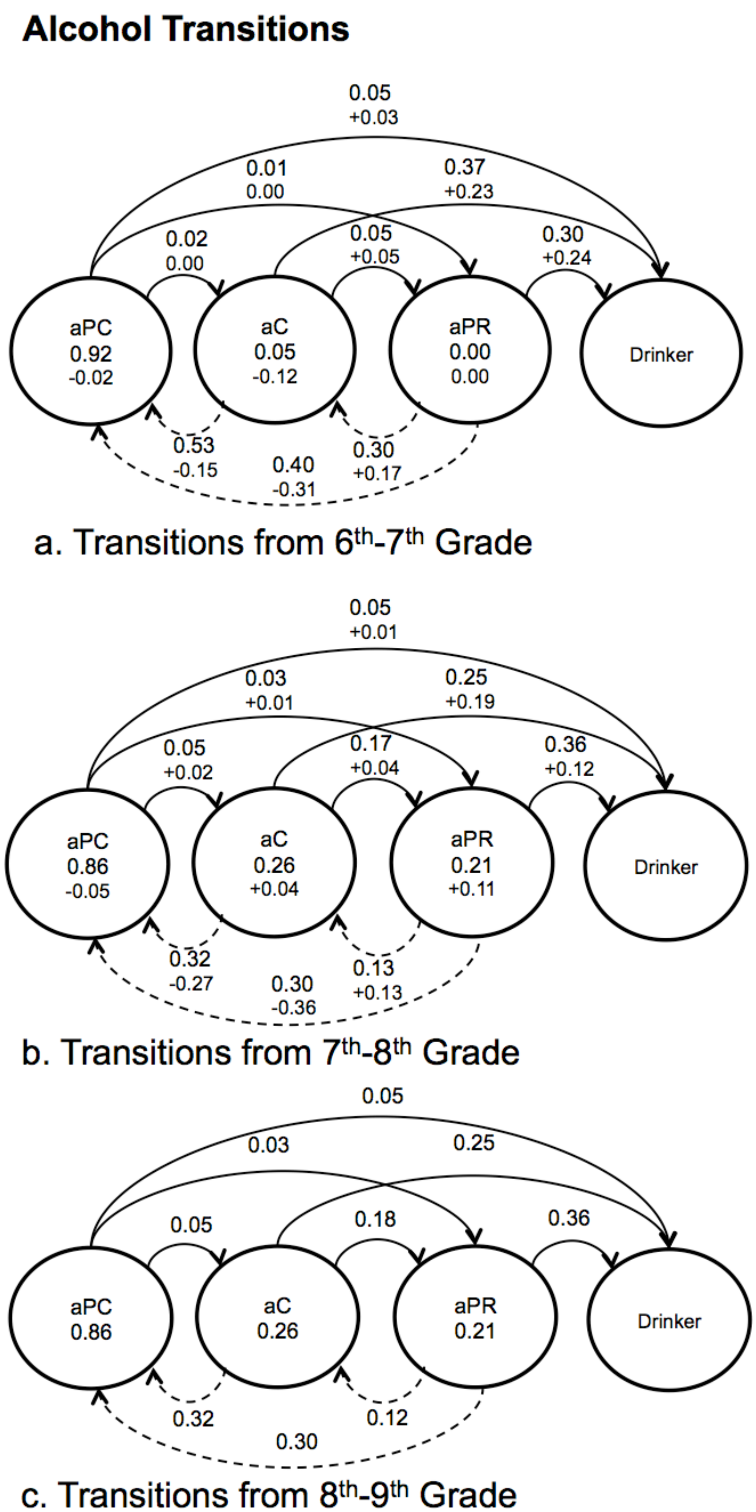

Figure 4. Transition probabilities in the substance use intervention for alcohol use. Note: aPC = acquisition Precontemplation; C= acquisition Contemplation; PR= acquisition Preparation; solid arrows indicate forward stage movement, dashed arrows indicate backwards stage movement; differences from comparison condition are presented below parameter estimates.

MANUSCRIPT 3

Gender differences in stage of change membership and transitions among adolescent physical activity and fruit and vegetable consumption

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Abstract.

Research has identified gender disparities among adolescent groups for physical activity and eating behaviors. Since these types of behaviors have critical health implications leading to chronic diseases like obesity, which also demonstrate gender differences, it is important to consider gender as a factor in the development of health promotion interventions. The current study evaluated differential effects of gender on Stage of Change progression in a large (N=4158) computer delivered, Transtheoretical Model-tailored multiple behavior intervention focusing on physical activity and fruit and vegetable consumption. Assessments began in sixth grade and continued yearly until eighth grade, with a follow-up in ninth grade. Therefore, given the known disparities for physical activity and diet behaviors across males and female adolescents, the current research aims to examine gender differences in stage membership and transitions. Latent Transition Analysis (LTA) was used to explore stage transitions across each of the behaviors using two approaches: multiple-group LTA across gender within each intervention condition and multiple group across intervention condition with gender as a covariate. Results indicate considerable differences in male and female physical activity as well as fruit and vegetable consumption. Males were more likely to be in, or transition into, Maintenance for physical activity and were more likely be in, or transition into, Precontemplation for fruit and vegetable consumption than females.

Gender differences in stage of change membership and transitions among adolescent physical activity and fruit and vegetable consumption

A growing body of research has identified gender disparities among adolescent groups for physical activity and eating behavior (Al-Hazzaa, Abahussain, Al-Sobayel, Qahwaji, & Musaiger, 2011; Butt, Weinberg, Breckon, & Claytor, 2011; Frenn et al., 2005; Ottevaere et al., 2011; Trost et al., 2002). One U.S. population based survey, which monitors health-risk behavior in high school students, reported that male students were more likely than female students to report eating fruit or drinking 100% fruit juices, eating vegetables, and physical activity (Kann et al., 2014). Research also indicates that physical activity (Dumith, Gigante, Domingues, & Kohl, 2011) and the consumption of fruit and vegetables decreases (Lien, Lytle, & Klepp, 2001) as adolescents transition to young adulthood, and may be greater and occur earlier in girls (Dumith et al., 2011). Since energy balance behaviors have critical health implications leading to chronic diseases like obesity, which has been shown to have significant gender differences due in part to biological and/or societal and cultural factors (Sweeting, 2008), it is crucial promote healthy energy balance behaviors early in life. In addition, adolescents are an important population for multiple behavior prevention, as behaviors related to obesity are shown to decline with age and being at risk for one unhealthy behavior increases the odds of being at risk for another unhealthy behavior (Driskell, Dyment, Mauriello, Castle, & Sherman, 2008).

School-based energy balance interventions, which focus on diet, physical activity, and sedentary behavior, represent key opportunities for health promotion in young people, but are few and have been met with mixed success (De Bourdeaudhuij et al., 2010; Ezendam, Brug, & Oenema, 2012; Lubans, Morgan, Callister, & Collins, 2009; Patrick et al., 2006; van Stralen et al., 2011). A systematic review of moderators in school-based interventions aimed at energy balance behaviors found that girls tended to respond better to interventions than boys (Yildirim et al., 2011). The authors suggest numerous reasons for this finding, including the tendency for boys to be more physically active, and therefore have less room for improvement, and the tendency for girls to have more concerns about body weight and body image, leading to more interest in intervention material. Other potential explanations include differences in social desirability, understanding of intervention materials, perceived and practical barriers, and perceived benefits.

A recent school-based Transtheoretical Model (TTM) intervention found significant positive effects for a computer delivered energy balance program for middle school students (Velicer et al., 2013). The study focused on promoting physical activity and fruit and vegetable consumption as well as reducing TV viewing. Briefly, the Transtheoretical Model (TTM) asserts that the variation in people's general readiness to change their behavior. Behavior change can be represented as a temporal sequence of behavioral and cognitive changes (Martin, Velicer, & Fava, 1996; Prochaska, 1983; Prochaska & Velicer, 1997; Velicer et al., 2000) with intentional change measured as the five ordered Stages of Change: Precontemplation (PC), Contemplation (C), Preparation (P), Action (A), and Maintenance (M) (Prochaska, Redding, & Evers, 2008; Prochaska & Velicer, 1997; Prochaska, Wright, & Velicer, 2008; Velicer et al., 2000). In addition, attitudes and beliefs about change are represented by other key psychological constructs, including Self-Efficacy (confidence), Decisional Balance (pros and cons), and the Processes of Change (Prochaska, 1983, 1994; Prochaska, Velicer, DiClemente, & Fava, 1988). Interventions serve to support healthy behavior by promoting Stage of Change progression. For example, the aforementioned school-based TTM intervention found that students who did not meet recommended criteria at the beginning of the intervention were more likely to initiate all three energy balance behaviors while students who were at criteria were less likely to relapse (Velicer et al., 2013). The study, however, did not consider potential gender differences in stage progression.

Latent Transition Analysis (LTA) has been used to characterize intervention effects in stage of change movement for energy balance behaviors in the same sample of adolescents (Brick et al., in preparation). LTA is a longitudinal approach that allows researchers to classify discrete change over time and is particularly useful with stage-sequential models such as the TTM (Collins & Lanza, 2010; Velicer, Martin, & Collins, 1996). By estimating the proportion of individuals in each stage, as well as the probability of transitioning to another stage, LTA can reveal stage movement patterns over the course of an intervention. It can also be used to model effects of covariates, such as gender, on stage membership and transition parameters (Lanza & Bray, 2010; Lanza & Collins, 2008). To date, gender differences in TTM stage membership and transitions have yet to be examined using an LTA framework. Therefore, given the known disparities for physical activity and diet behaviors across males and female adolescents, the current research aims to examine gender differences in stage prevalence and transitions using two approaches: multiple-group LTA across gender within intervention condition and multiple-group LTA across intervention condition with gender as a covariate.

Methods

Sample

Students (N=4158) were eligible to participate if they were in sixth grade at the time of study and spoke English. Data were collected from middle schools across Rhode Island, which were matched on available school-level data (e.g. percent free lunch eligible, percent English as second language, percent attending college, racial/ethnic composition, smoking rate, and alcohol use rate) and randomized by school to one of two treatment groups (described below). A total of 20 middle schools across Rhode Island participated in the study and consisted of 47.8% female, 65.0% White, 15.6% Hispanic, 3.8% Black, 2.4% Asian, 2.2% American Indian/Alaskan Native, 0.5% Pacific Islander students, with the remaining students reporting unknown or a combination of ethnicities (Velicer et al., 2013).

Intervention design

Two TTM interventions were disseminated with ten schools receiving an energy balance intervention and ten receiving a comparison intervention that focused on substance use prevention. Details regarding TTM-based multiple health behavior intervention for adolescents has been published elsewhere (Mauriello et al., 2010; Velicer et al., 2013). Students in the energy balance intervention received multiple health behavior feedback with fully tailored feedback for physical activity and moderately or minimally tailored feedback for fruit and vegetable consumptions and sedentary behavior (i.e. TV viewing). Students in the comparison intervention were provided tailored feedback on prevention or reduction of tobacco and alcohol use. Both interventions received computerized assessment and TTM-tailored intervention material using multimedia components (Redding et al., 1999; Velicer et al., 2013), with each intervention condition serving as the comparison condition for the other. Five 30-minute computerized TTM-tailored sessions were used to disseminate intervention material and four yearly assessments were conducted to determine student progress. One intervention session took place during sixth grade, three in seventh grade, and one in eighth grade. Assessment occurred early in the academic year for all grades. For more detail regarding study design and outcomes, see Velicer et al. (2013).

Measures

Stage of Change. The current study focused on membership and transitions with respect to Stage of Change for physical activity as well as fruit and vegetable consumption. The Stage of Change algorithm that was used for each of the behaviors has been previously validated (Mauriello et al., 2010). Criteria for Stage of Change is as follows: (1) Precontemplation (PC; not meeting behavioral criteria and not planning to meet criteria in the next 6 months), (2) Contemplation (C; not meeting behavioral criteria but planning to meet criteria in the next 6 months), (3) Preparation (PR; not meeting behavioral criteria but planning to meet criteria in the next 30 days), (4) Action (A; meeting behavioral criteria for less than 6 months), and (5) Maintenance (M; meeting behavioral criteria for more than 6 months). Membership in PC, C, or PR is considered “pre-action”, as these stages represent levels of readiness to change before action has been taken to modify behavior.

The staging algorithm used verification with specific behavioral criteria prior to asking about behavior intention to reduce staging misclassification error. Specific criteria for each behavior were based on national guidelines (U.S. Department of Agriculture and U.S. Department of Health and Human Services, 2010) as follows, physical activity (at least 60 min of physical activity for at least 5 days per week) and fruit and vegetable consumption (at least five servings of fruits and vegetables each day). Therefore, if a participant did not report engaging in 60 minutes of physical activity at least five days a week, they were asked about their intention to being engaging in physical activity to determine which pre-action stage they belonged to and could not be considered in A or M.

Gender. Students' self-reported gender was assessed with a single item in which they identified themselves as either "male" or "female". Males were coded as the reference group for all covariate models.

Statistical Analyses

Latent Transition Analysis. Latent Transition Analysis involves the estimation of large and complex models, thus a brief note on terminology is merited. Three types of parameters were estimated, including delta (the stage membership probability or prevalence), tau (the transition probability, conditional on previous stage membership), and rho (the item-response probability for a given stage). At each time point, delta parameters were estimated to determine stage membership probabilities and tau parameters between time points are estimated to determine transition probabilities conditional on previous stage membership. For the current study, it is noted that the rho matrices for all models were identical, with values fixed to invariance across time and all matrices present each Stage of Change as a single item indicator for each status.

The current study took place over a four-year period spanning from sixth to ninth grade, with annual assessments. The ninth grade assessment represents a follow-up administered without intervention material. Thus, there were three transition periods of interest representing the transition between sixth and seventh grade, the transition between seventh and eighth grade, and the follow-up transition between eighth and ninth grade.

All statistical analyses were conducted in SAS version 9.3 using PROC LTA (PROC LCA & PROC LTA [Version 1.3.0], 2013). The Goodness of Fit statistic G^2, which is approximately distributed as chi-squared, was used to assess model fit (Collins & Lanza, 2010; Velicer et al., 1996). In addition, due to known limitations of the chi-squared distribution with large sample sizes, the AIC and BIC were also presented assess and compare model fit. The full information maximum likelihood technique accounted for missing data due to attrition or missed school days when data was collected.

Two approaches were used to investigate gender disparities in physical activity and fruit and vegetable consumption. First, gender differences within intervention condition were investigated using gender as a grouping variable in multiple group models for the energy balance and the comparison interventions separately. Next, gender was entered as a covariate in a multiple-group model to predict baseline stage membership and transitions across intervention condition. A binary logistic model was specified to facilitate interpretation and reduce model complexity (Collins & Lanza, 2010). Odd ratios obtained from this model elucidate the likelihood of stage membership and transitions with reference to being male. It should be noted that PROC LTA does not currently provide standard error estimates for LTA model parameters or odds ratios. However, Cohen's d effect size was calculated from the odds ratios (Sánchez-Meca, Marín-Martínez, & Chacón-Moscoso, 2003) with classification of $d = |0.20|$ as small, $d = |0.50|$ as medium, and $d = |0.8|$ as large (Cohen, 1988).

Results

Physical activity

Intervention specific effects across gender. To examine model parameters conditional on gender and to explore potential differences between male and female stage distributions, gender was entered as a grouping variable in a multiple group model. No constraints were placed on stage movement in this model, thus students were free to transition or stay in any stage. Model fit for physical activity stage transitions for both interventions is presented in Table 1. Stage membership probabilities (delta estimates) for the energy balance and comparison conditions are presented in Table 2. For both genders at baseline (i.e. sixth grade), roughly half of the students reported being in M. Estimates indicate that this value was slightly higher for males (0.54) than for females (~0.42-0.44). For males, membership in M in the energy balance intervention remained high over time but decreased slightly in the comparison condition. For females, this value declined in both the intervention and comparison condition, though the decline was greater in the comparison condition. Females were more likely than males to be in PR at baseline for both intervention conditions, suggesting that female students are thinking about planning to change but may be having a harder time making the changes relative to the male students. Membership in PC was low for both genders, with slightly higher probabilities observed in the comparison intervention.

Transition probabilities (tau estimates) are presented separately for the intervention and comparison condition in Tables 3 and 4, respectively. In the energy balance condition, males had higher probabilities of transitioning into M than females, and had higher probabilities of staying in M than females. Both had low probabilities of transitioning into PC and tended to have lower probabilities in the lower diagonal of the transition matrix, indicating that few students regressed to a lower level of readiness to change (i.e. towards PC). In addition, both males and females showed zero probabilities of moving into M from a pre-action stage at the ninth grade follow-up.

Transition probabilities in the comparison condition reveal differences from the energy balance intervention. No participants from a pre-action stage (i.e. PC, C, or PR) transitioned into M during any of the three transitions. This pattern was seen in the intervention condition during the follow-up period, suggesting that the program may be successfully promoting stage movement during the intervention. Males tended to have higher probabilities of moving into M from A or staying in M than females. Both males and females had relatively high probabilities of moving into A and the probabilities for moving backward from M to A were low.

Gender effects across intervention condition. Gender was then added as a covariate in a binary logistic two-group model across intervention condition. Given that gender differences were observed among stage membership in M in the previous step, and that M represents a desirable outcome, M was assigned as the reference group for binary transition comparisons. Gender was a significant predictor of stage membership at baseline (change in 2*loglikelihood from baseline model = 46.48, degrees of freedom = 2, $p < 0.0001$). Table 5 shows parameter estimates and odds ratios corresponding to the association between gender and baseline stage membership and transitions from grades six to nine across energy balance and comparison interventions. Cohen's d effect size was calculated from the odd ratios (Sánchez-Meca, Marín-Martínez, & Chacón-Moscoso, 2003) and is also included in Table 5. Since M was specified as the binary reference group, the stage membership coefficients represent the change in log-odds of membership in M relative to all other stages and the transition coefficients represent the change in log-odds of transitioning into M from each of the other stages or staying in M. For both intervention conditions at baseline, compared to females, males had slightly higher odds of being in M versus any other stage (odds $\text{ratio}_{\text{intervention}} = 1.60$; odds $\text{ratio}_{\text{comparison}} = 1.45$), though these effects were very small (Cohen's $d_{\text{intervention}} = 0.11$, Cohen's $d_{\text{comparison}} = 0.09$). Many odds ratios for stage transitions over time were close to 1 with very small Cohen's d values, indicating negligible gender differences. However, a few higher values were observed. In the energy balance intervention, males had five times the odds of transitioning from PC to M during the period from sixth to seventh grade (small/medium Cohen's d = 0.39). This effect was not observed in the comparison condition. Males in the energy balance condition had over two times the odds of transitioning from PR to M during the transitions from grades seven to nine compared to females (small Cohen's d = 0.21-0.24). Odds ratios show an overall tendency for males to be more apt to transition into M compared to females, with slightly larger effect sizes in the energy balance intervention.

Fruit and vegetable consumption

Intervention specific effects across gender. Gender was entered as a grouping variable in a multiple group model to obtain parameter estimates specific to males and females. No constraints were placed on stage movement in this model, thus students were free to transition or stay in any stage. Model fit results for fruit and vegetable consumption stage transitions are presented in Table 1. Stage membership probabilities (delta estimates) for the energy balance and comparison conditions are presented in Tables 2. For both genders, the stage with the highest membership probability was PR (~0.31-0.40). Estimates indicate that females had a slightly higher probability of being in M (~0.26-0.30) at baseline than males (~0.24), but these values for both groups decreased over time. Membership in A, however, started low for all groups (~0.03-0.05) and steadily increased (~0.10-0.13). This suggests that even though students may not have reached M, the most desirable outcome, many of them were in A for fruit and vegetable consumption. More males were in PC at baseline (~0.15-0.20) than females (~0.09-0.10), and membership in PC for both increased more in the comparison group than the intervention group over time.

Transition probabilities (tau estimates) are presented separately for the intervention and comparison condition in Tables 6 and 7, respectively. In the energy balance condition males and females had moderate probabilities of staying in M that increased over time, despite the decrease in membership in that stage. Both groups also demonstrated moderate probabilities of staying in PC, which appears to increase over time for males and appears to be larger than for females. Both tended to have low probabilities of transitioning into PC, with females demonstrating slightly lower transition probabilities. Overall, the pattern tended towards lower probabilities in the lower diagonal of the transition matrix, indicating that fewer students regress backwards towards PC than move forward toward M. In addition, and consistent with findings from physical activity stages, both males and females showed zero probabilities of moving into M from a pre-action stage at the ninth grade follow-up.

Transition probabilities in the comparison condition reveal some differences from the energy balance intervention. No participants from a pre-action stage (i.e. PC, C, or PR) transitioned into M during any of the three transitions. This pattern was seen in the intervention condition during the follow-up period, suggesting that the program may be successfully promoting stage movement during the intervention, and was also observed in physical activity stages. Both males and females had high probabilities of staying in M, and of staying in a given stage in general. Over time, males appear to have higher probabilities of transitioning into or staying in PC than females.

Gender effects across intervention condition. Gender was added as a covariate in a binary logistic two-group model across intervention condition. PC was chosen as the references group due to differences observed in the multiple-group model from the previous step. Gender was a significant predictor of stage membership at baseline (change in 2*loglikelihood from baseline model = 57.39, degrees of freedom = 2, $p<0.0001$). Table 5 shows parameter estimates, odds ratios, and effect size estimates (Cohen's d) corresponding to the association between gender and baseline stage membership and stage transitions grades six to nine across energy balance and comparison interventions. Since PC was specified as the binary reference group, the stage membership coefficients represent the change in log-odds of membership in PC relative to all other stages and the transition coefficients represent the change in log-odds of transitioning into PC from each of the other stages or staying in PC. For both intervention conditions, compared to females, males were slightly more likely to be in PC versus any other stage at baseline (odds $\text{ratio}_{\text{intervention}}$ = 1.86; odds $\text{ratio}_{\text{comparison}}$ = 2.16), though the effects were small (Cohen's $d_{\text{intervention}}$ = 0.15, Cohen's $d_{\text{comparison}}$ = 0.19). Many odds ratios for stage transitions were close to 1, with very small Cohen's d values, indicating negligible gender differences. However, a few high values were observed. During the transition from sixth to seventh grade, the odds for males in the energy balance group were more than 18 times greater than females to transition backwards from A to PC (medium/large Cohen's d = 0.70), and the odds were more than 3 times greater than females to transition backwards from M to PC during the transitions from seventh to ninth grades (small Cohen's d = 0.27-0.31). Males also had 2 times the odds of transitioning from A to PC during the intervention follow-up from eighth to ninth grade (small Cohen's d = 0.20). These effects were larger in the intervention group compared to the comparison group.

Discussion

This study is the first to examine effects of gender on TTM stage transitions using LTA and highlights two approaches for examining gender differences in physical activity and fruit and vegetable consumption. LTA was used in both approaches to model discrete changes in adolescents' readiness to engage in and maintain health behavior change from grades six to nine, conditional on membership in one of two school-based behavioral interventions. Multiple-group models revealed gender differences in baseline stage membership and transitions between males and females within each intervention and multiple-group binary logistic transition models further supported the differential effects of gender as a covariate on stage membership and transitions across intervention condition.

The data from this study demonstrate that about half of all students report being in M for physical activity in sixth grade. However, males had a higher probability of being in M for physical activity than females. Examination of the stage membership and transition parameters revealed that females tended to have lower rates of staying in and transitioning into M. Gender differences were reiterated in the covariate models in that males were more likely than females to be in M at baseline compared to all other stages for both intervention groups. Males also demonstrated a tendency towards higher odds of transitioning to M, especially in the energy balance intervention, compared to females. Female students had higher rates of being in PR than males and lower odds of transitioning to M, suggesting that female students are thinking about changing but may be having a harder time making the changes relative to the male students.

Models investigating stage of change for fruit and vegetable consumption revealed slightly different patterns than physical activity. The stage distribution for this behavior was markedly different. At baseline, males had a higher probability of being in PC than females. This finding was also supported in the covariate models such that males were more likely than females to be in PC at baseline compared to all other stages for both intervention groups. Contrary to the goal of the intervention, males also demonstrated a tendency towards higher odds of transitioning back to PC from A and M in the energy balance intervention. Examination of the stage membership and transition parameters also revealed that females tended to have lower rates of membership in PC and that membership in PC was higher for both males and females in the comparison intervention.

Collectively, the results from this study indicate that males and female adolescents differ in their readiness to engage in and maintain physical activity and fruit and vegetable consumption behaviors, and that they may experience differential intervention effects. These findings are consistent with other research that suggests that males and females exhibit different physical activity and eating behaviors and that they may respond differently to health behavior interventions. For example, gender differences in adolescent physical activity have been linked to higher levels of teasing and body image concern in girls (Slater & Tiggemann, 2011) as well as lower participations in organized sports (Vilhjalmsson & Kristjansdottir, 2003). Future studies could look at differences in self-efficacy between males and females and how it may influence stage progression and behavior change. In addition, meta-analyses have discovered larger effects among interventions that jointly focused on diet and physical activity and for interventions that targeted girls specifically, rather than girls and boys together (Biddle, Braithwaite, & Pearson, 2014). Thus, female students may benefit from a more integrated, gender-specific approach. While research has supported individual tailoring of intervention feedback (Noar, Benac, & Harris, 2007;

Rimer & Kreuter, 2006), it may be possible for school-based studies to achieve better results by providing gender targeted feedback. For example, given the finding that females tend to have lower transitions into M for physical activity, interventions could provide additional support or tips for adolescent girls to help them maintain their physical activity. Similarly, given the finding that males had higher probabilities of regressing back into PC from A or M, future interventions may want to provide more support towards maintenance of healthy eating behaviors for boys.

Some limitations to this study include that all measures in the study rely on self-reported behavior, which may introduce measurement error, and the study was not able to utilize a true no-treatment control group, preventing the ability to model natural or normative changes in adolescent physical activity and fruit and vegetable consumption. Consideration for the lack of a no-treatment control group is discussed further in Velicer et al. (2013), as this approach was able to maximize school participation and could meet curriculum demands. Further, the approach used in this study characterized stage as a manifest variable indicated by a single item (i.e. the result of the staging algorithm). Therefore, the model does not incorporate measurement error and future studies may consider using multiple measures of to represent stage as a truly "latent" variable.

Other demographic factors like race/ethnicity and socioeconomic status (SES) likely play a role in both physical exercise and/or eating behaviors. One study found that physical activity in late adolescence and early adulthood was positively associated with higher levels of SES (Walters, Barr-Anderson, Wall, & Neumark-Sztainer, 2009). Future studies could look at differential effects of the energy balance and comparison intervention on stage membership and transitions between different levels of SES or racial/ethnic groups.

Given the implications for the reduction of health behavior risks that lead to serious diseases like obesity, it is essential for health researchers to consider the complex relationship between behavior, health, and gender. The interplay between these components may affect intervention responsiveness and behavior change success. Researchers developing TTM-based studies should be sensitive to gender specific considerations when designing stage-matched exercise (Fallon, Hausenblas, & Nigg, 2005) and diet interventions. More research is needed in this area to better characterize underlying factors for gender differences and for methods and approaches to reduce these disparities.

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Tables and Figures

Table 1. Model fit for physical activity and fruit and vegetable consumption stage models across gender.

Intervention	DF	-LL	G^2	AIC	BIC
Physical Activity					
Intervention	2097023	-8822.62	915.10	1171.10	1898.58
Comparison	2097023	-7780.03	776.79	1032.79	1747.51
Fruit and Vegetable Consumption					
Intervention	2097023	-9761.80	1005.64	1261.64	1989.11
Comparison	2097023	-8751.41	810.81	1066.81	1781.53

Note: DF = degrees of freedom; -LL = -2 log likelihood; AIC = Akaike Information Criteria; BIC = Bayesian Information Criteria.

Table 2. Model estimated group membership probabilities for physical activity and fruit and vegetable consumption stages across gender.

		PC		C		PR		A		M	
Intervention	**Grade**	**Male**	**Female**	**Male**	**Female**	**Male**	**Female**	**Male**	**Female**	**Male**	**Female**
Physical Activity											
Energy Balance	6th	0.09	0.07	0.11	0.15	0.17	0.27	0.09	0.09	0.54	0.42
	7th	0.06	0.04	0.12	0.14	0.15	0.27	0.18	0.21	0.50	0.34
	8th	0.06	0.06	0.09	0.16	0.12	0.30	0.14	0.09	0.60	0.39
	9th	0.07	0.05	0.10	0.18	0.12	0.23	0.16	0.23	0.55	0.31
Comparison	6th	0.07	0.08	0.12	0.14	0.20	0.28	0.07	0.06	0.54	0.44
	7th	0.08	0.10	0.12	0.17	0.15	0.24	0.21	0.19	0.44	0.30
	8th	0.10	0.13	0.10	0.15	0.15	0.27	0.20	0.17	0.45	0.28
	9th	0.10	0.12	0.13	0.20	0.14	0.26	0.18	0.17	0.45	0.25
Fruit and Vegetable Consumption											
Energy Balance	6th	0.15	0.09	0.23	0.22	0.33	0.36	0.04	0.03	0.25	0.30
	7th	0.12	0.08	0.23	0.20	0.26	0.40	0.18	0.13	0.21	0.20
	8th	0.14	0.10	0.22	0.19	0.25	0.37	0.08	0.06	0.31	0.29
	9th	0.18	0.10	0.23	0.25	0.26	0.35	0.12	0.10	0.21	0.20
Comparison	6th	0.20	0.10	0.22	0.19	0.31	0.40	0.04	0.05	0.24	0.26
	7th	0.23	0.16	0.23	0.22	0.29	0.35	0.13	0.15	0.12	0.12
	8th	0.28	0.20	0.23	0.26	0.25	0.33	0.13	0.09	0.11	0.12
	9th	0.29	0.18	0.24	0.28	0.22	0.34	0.13	0.11	0.11	0.09

Note: PC = Precontemplation; C= Contemplation; PR= Preparation; A = Action; M = Maintenance.

Table 3. Model parameters for gender based physical activity stage transitions within the energy balance intervention.

		Stage in 7th Grade									
		PC		**C**		**PR**		**A**		**M**	
		Male	**Female**	**Male**	**Female**	**Male**	**Female**	**Male**	**Female**	**Male**	**Female**
	PC	0.21	0.27	0.16	0.28	0.18	0.24	0.18	0.15	0.27	0.06
	C	0.09	0.05	0.24	0.26	0.22	0.31	0.20	0.23	0.25	0.15
Stage in 6th Grade	**PR**	0.05	0.02	0.16	0.14	0.25	0.42	0.26	0.21	0.28	0.20
	A	0.06	0.03	0.23	0.13	0.11	0.30	0.24	0.30	0.38	0.25
	M	0.03	0.01	0.06	0.08	0.09	0.16	0.14	0.18	0.67	0.56
		Stage in 8th Grade									
	PC	0.44	0.40	0.16	0.15	0.10	0.18	0.09	0.07	0.22	0.19
	C	0.09	0.10	0.25	0.38	0.19	0.28	0.27	0.11	0.21	0.13
Stage in 7th Grade	**PR**	0.02	0.03	0.07	0.20	0.29	0.50	0.27	0.10	0.36	0.17
	A	0.04	0.06	0.10	0.11	0.12	0.26	0.16	0.13	0.58	0.44
	M	0.02	0.01	0.03	0.06	0.05	0.18	0.07	0.07	0.83	0.67
		Stage in 9th Grade									
	PC	0.37	0.40	0.28	0.30	0.08	0.16	0.27	0.14	0.00	0.00
	C	0.13	0.07	0.38	0.31	0.19	0.29	0.30	0.33	0.00	0.00
Stage in 8th Grade	**PR**	0.06	0.01	0.16	0.21	0.25	0.39	0.53	0.39	0.00	0.00
	A	0.08	0.10	0.13	0.23	0.13	0.11	0.19	0.20	0.47	0.35
	M	0.03	0.01	0.02	0.07	0.09	0.12	0.05	0.08	0.81	0.72

Note: PC = Precontemplation; C= Contemplation; PR= Preparation; A = Action; M = Maintenance.

Table 4. Model parameters for gender based physical activity stage transitions within the comparison intervention.

		Stage in 7th Grade									
		PC		C		PR		A		M	
		Male	Female	Male	Female	Male	Female	Male	Female	Male	Female
	PC	0.38	0.38	0.14	0.17	0.12	0.20	0.36	0.25	0.00	0.00
	C	0.11	0.17	0.30	0.29	0.16	0.24	0.44	0.30	0.00	0.00
Stage in 6th Grade	PR	0.07	0.08	0.20	0.23	0.28	0.34	0.45	0.35	0.00	0.00
	A	0.10	0.06	0.07	0.12	0.24	0.27	0.07	0.24	0.52	0.30
	M	0.04	0.04	0.06	0.10	0.10	0.18	0.06	0.04	0.74	0.64
		Stage in 8th Grade									
	PC	0.43	0.52	0.10	0.14	0.05	0.14	0.43	0.21	0.00	0.00
	C	0.13	0.12	0.21	0.29	0.24	0.26	0.42	0.33	0.00	0.00
Stage in 7th Grade	PR	0.12	0.10	0.13	0.14	0.27	0.48	0.48	0.28	0.00	0.00
	A	0.10	0.11	0.11	0.19	0.19	0.27	0.10	0.08	0.50	0.35
	M	0.02	0.05	0.05	0.05	0.09	0.14	0.03	0.05	0.80	0.71
		Stage in 9th Grade									
	PC	0.47	0.47	0.20	0.21	0.08	0.15	0.25	0.18	0.00	0.00
	C	0.08	0.12	0.36	0.35	0.08	0.24	0.48	0.28	0.00	0.00
Stage in 8th Grade	PR	0.05	0.06	0.17	0.21	0.35	0.42	0.43	0.31	0.00	0.00
	A	0.09	0.06	0.16	0.17	0.20	0.32	0.08	0.11	0.47	0.35
	M	0.03	0.04	0.05	0.12	0.07	0.14	0.05	0.03	0.80	0.67

Note: PC = Precontemplation; C= Contemplation; PR= Preparation; A = Action; M = Maintenance.

Table 5. Parameter estimates and odds ratios for gender as a covariate predicting baseline stage membership and transitions.

	Comparison	Intervention β	Intervention OR	Intervention d	Comparison β	Comparison OR	Comparison d
Physical Activity							
Baseline Stage Membership	M vs. all others	0.47	1.60	0.11	0.37	1.45	0.09
6th to 7th Grade	PC to M	1.64	5.17	0.39	0.07	1.07	0.02
	C to M	0.63	1.88	0.15	0.08	1.09	0.02
	PR to M	0.43	1.54	0.10	0.26	1.29	0.06
	A to M	0.61	1.85	0.15	0.91	2.48	0.22
	Stay in M	0.47	1.60	0.11	0.47	1.59	0.11
7th to 8th Grade	PC to M	0.15	1.16	0.04	0.17	1.19	0.04
	C to M	0.53	1.71	0.13	0.28	1.33	0.07
	PR to M	0.99	2.69	0.24	0.34	1.41	0.08
	A to M	0.53	1.69	0.13	0.63	1.88	0.15
	Stay in M	0.86	2.37	0.21	0.51	1.67	0.12
8th to 9th Grade	PC to M	-0.13	0.88	-0.03	0.30	1.35	0.07
	C to M	0.51	1.66	0.12	0.29	1.34	0.07
	PR to M	0.86	2.36	0.21	0.54	1.71	0.13
	A to M	0.58	1.79	0.14	0.57	1.78	0.14
	Stay in M	0.53	1.69	0.13	0.64	1.90	0.15
Fruit and Vegetable Consumption							
Baseline Stage Membership	PC vs. all others	0.62	1.86	0.15	0.77	2.17	0.19
6th to 7th Grade	Stay in PC	-0.15	0.86	-0.04	-0.08	0.92	-0.02
	C to PC	0.67	1.96	0.16	0.20	1.22	0.05
	PR to PC	0.65	1.91	0.16	0.57	1.76	0.14
	A to PC	2.92	18.48	0.70	-0.58	0.56	-0.14
	M to PC	0.23	1.26	0.06	0.26	1.29	0.06
7th to 8th Grade	Stay in PC	0.07	1.08	0.02	0.33	1.39	0.08
	C to PC	0.37	1.45	0.09	0.36	1.43	0.09
	PR to PC	0.58	1.79	0.14	0.48	1.61	0.11
	A to PC	-0.36	0.70	-0.09	0.02	1.02	0.01
	M to PC	1.30	3.68	0.31	0.67	1.95	0.16
8th to 9th Grade	Stay in PC	0.60	1.82	0.14	0.50	1.65	0.12
	C to PC	0.42	1.52	0.10	0.66	1.93	0.16
	PR to PC	0.44	1.55	0.10	0.20	1.22	0.05
	A to PC	0.85	2.33	0.20	0.55	1.73	0.13
	M to PC	1.13	3.11	0.27	1.17	3.22	0.28

Note: PC = precontemplation; C= contemplation; PR= preparation; A = action; M = maintenance; OR = odds ratio; d = Cohen’s d effect size; Male is the reference group for all comparisons.

Table 6. Model parameters for gender based fruit and vegetable consumption stage transitions within the energy balance intervention.

		Stage in 7th Grade									
		PC		C		PR		A		M	
		Male	Female	Male	Female	Male	Female	Male	Female	Male	Female
Stage in 6th Grade	PC	0.31	0.35	0.34	0.26	0.13	0.20	0.12	0.06	0.10	0.12
	C	0.12	0.07	0.29	0.27	0.29	0.43	0.21	0.12	0.09	0.11
	PR	0.09	0.05	0.21	0.20	0.37	0.50	0.18	0.12	0.15	0.13
	A	0.09	0.00	0.14	0.10	0.30	0.52	0.19	0.26	0.28	0.12
	M	0.05	0.04	0.13	0.12	0.18	0.29	0.18	0.16	0.46	0.38
		Stage in 8th Grade									
Stage in 7th Grade	PC	0.49	0.46	0.24	0.26	0.13	0.19	0.06	0.04	0.09	0.05
	C	0.18	0.14	0.40	0.35	0.25	0.35	0.05	0.06	0.11	0.11
	PR	0.09	0.05	0.22	0.17	0.43	0.55	0.08	0.07	0.18	0.16
	A	0.06	0.08	0.16	0.16	0.21	0.30	0.14	0.08	0.43	0.38
	M	0.02	0.01	0.07	0.06	0.14	0.17	0.06	0.04	0.72	0.73
		Stage in 9th Grade									
Stage in 8th Grade	PC	0.52	0.36	0.22	0.44	0.13	0.14	0.14	0.06	0.00	0.00
	C	0.18	0.13	0.42	0.43	0.29	0.34	0.11	0.10	0.00	0.00
	PR	0.09	0.06	0.24	0.24	0.43	0.53	0.23	0.17	0.00	0.00
	A	0.18	0.08	0.14	0.28	0.23	0.35	0.10	0.06	0.36	0.23
	M	0.10	0.03	0.13	0.10	0.15	0.20	0.04	0.03	0.58	0.64

Note: PC = Precontemplation; C= Contemplation; PR= Preparation; A = Action; M = Maintenance.

Table 7. Model parameters for gender based fruit and vegetable consumption stage transitions within the comparison intervention.

		PC		C		PR		A		M	
		Male	**Female**	**Male**	**Female**	**Male**	**Female**	**Male**	**Female**	**Male**	**Female**
						Stage in 7th Grade					
Stage in 6th Grade	**PC**	0.46	0.49	0.21	0.20	0.20	0.17	0.12	0.14	0.00	0.00
	C	0.23	0.19	0.32	0.27	0.27	0.33	0.18	0.21	0.00	0.00
	PR	0.19	0.12	0.24	0.24	0.37	0.45	0.21	0.20	0.00	0.00
	A	0.07	0.12	0.24	0.16	0.30	0.26	0.04	0.19	0.36	0.27
	M	0.11	0.09	0.16	0.18	0.28	0.29	0.03	0.02	0.43	0.42
						Stage in 8th Grade					
Stage in 7th Grade	**PC**	0.57	0.49	0.18	0.30	0.12	0.18	0.13	0.03	0.00	0.00
	C	0.26	0.19	0.35	0.40	0.24	0.29	0.14	0.12	0.00	0.00
	PR	0.19	0.12	0.21	0.21	0.41	0.50	0.20	0.16	0.00	0.00
	A	0.18	0.17	0.18	0.20	0.22	0.26	0.07	0.02	0.35	0.35
	M	0.13	0.07	0.16	0.14	0.18	0.23	0.02	0.02	0.51	0.54
						Stage in 9th Grade					
Stage in 8th Grade	**PC**	0.60	0.48	0.21	0.26	0.09	0.16	0.10	0.09	0.00	0.00
	C	0.24	0.14	0.32	0.44	0.24	0.30	0.20	0.12	0.00	0.00
	PR	0.11	0.09	0.28	0.27	0.40	0.48	0.21	0.16	0.00	0.00
	A	0.20	0.12	0.18	0.22	0.23	0.30	0.03	0.05	0.36	0.31
	M	0.14	0.04	0.16	0.08	0.08	0.34	0.04	0.03	0.59	0.50

Note: PC = Precontemplation; C= Contemplation; PR= Preparation; A = Action; M = Maintenance.

APPENDICES

Appendices Outline

APPENDIX A: INTRODUCTION

The overarching goal of this dissertation is to highlight and characterize Transtheoretical Model (TTM) Stage of Change transitions in energy balance and substance use behaviors in a large adolescent population over four years. Latent Transitions Analysis (LTA; discussed in Appendix B) was employed to determine stage membership and transitions for five health behaviors, including physical activity, fruit and vegetable consumption, TV viewing, smoking, and alcohol use. In Appendix A, an overview of adolescent health issues, with special consideration given to gender disparities found in physical activity and diet behaviors, is provided. A brief discussion of school-based health behavior interventions, as well as the theory underlining the TTM, is also included.

Adolescent health: energy balance and substance use prevention

The transition from childhood to adolescence is a crucial period for the development and promotion of healthy behaviors to be sustained into adulthood (Park, Scott, Adams, Brindis, & Irwin, 2014). These behaviors can help to set the groundwork for prevention of chronic diseases like obesity, cancer, and substance abuse. National initiatives, like *Healthy People 2010* in the United States, have begun to promote healthy behavior in all Americans by increasing the quality of healthy years of life and reducing health disparities, with focus towards adolescent health promotion to help reduce the development of chronic diseases in later adulthood (Brindis et al., 2004).

Of special consideration for adolescent populations are energy balance behaviors, like physical activity, diet, and sedentary behavior, and substance use behaviors, like smoking and alcohol use. For example, physical activity and fitness in adolescence, particularly aerobic exercise, has been linked to young adulthood cardiovascular disease risk factor level (Hasselstrøm, Hansen, Froberg, & Andersen, 2002). Research also suggests that decreases in fruit consumption, hours of physical education, and frequency of sports participation were associated with higher increases in standardized scores of Body Mass Index (Haerens, Vereecken, Maes, & De Bourdeaudhuij, 2010). In addition, the health impacts of smoking have been long established, with nearly nine out of 10 smokers report starting before the age of 18 and most before the age of 27 (U.S. Department of Health and Human Services, 2014). Adolescents who begin drinking prior to the age of 15 are four more times likely to develop alcohol dependence when compared to individual who began drinking after the age of 20 (Grant & Dawson, 1997). Indeed, the choices and behaviors made in adolescence can have long-term health implications.

Unfortunately, research suggests that many adolescents are not engaging in many healthy behaviors at recommended levels, such a diet and exercise, and that some of these behaviors decrease during adolescence (U.S. Department of Agriculture and U.S. Department of Health and Human Services, 2010). For example, some studies have found that that physical activity (Dumith, Gigante, Domingues, & Kohl, 2011) and the consumption of fruit and vegetables decreases (Lien, Lytle, & Klepp, 2001) as adolescents transition to young adulthood. Reports from the National Youth Risk Behavior Survey (YRBS) indicate that 41.3% of students played video or computer games or used a computer for work not related to school for more than three hours per day and that 32.5% reported watching television for three or more hours per day on an average school day (Kann et al., 2014). Furthermore, research has demonstrated that being at risk for one unhealthy behavior tends to increase the odds of being at risk for another unhealthy behavior (Driskell, Dyment, Mauriello, Castle, & Sherman, 2008). Finally, cigarette smoking represents the largest preventable cause of death in the United States while alcoholic beverages represent the most common psychoactive substance used by young people in the United States (Johnston, O'Malley, Bachman, & Schulenberg, 2012).

Gender differences in physical activity and diet

In addition to a general focus on adolescent health across a number of risk areas, this dissertation contributes to a growing body of research has identified gender disparities among adolescent groups for physical activity and diet behavior (Al-Hazzaa, Abahussain, Al-Sobayel, Qahwaji, & Musaiger, 2011; Butt, Weinberg, Breckon, & Claytor, 2011; Frenn et al., 2005; Ottevaere et al., 2011; Trost et al., 2002). One population based survey in the United States that monitors health-risk behavior in high school students reported that male students were more likely to report eating fruit or drinking 100% fruit juices, eating vegetables, and behaviors that increase physical activity (Kann et al., 2014). Research also indicates that physical activity (Dumith et al., 2011) and the consumption of fruit and vegetables decreases (Lien et al., 2001) as adolescents transition to young adulthood, and may be greater and occur earlier in girls (Dumith et al., 2011). Since these types of behaviors have critical health implications potentially leading to obesity, a major public health concern shown to have significant gender differences due in part to biological and/or societal and cultural factors (Sweeting, 2008), it is crucial promote healthy behaviors early in life. Furthermore, adolescents are an important population for multiple behavior obesity prevention, as behaviors related to obesity prevention are shown to decline with age and being at risk for one unhealthy behavior tends to increase the odds of being at risk for another unhealthy behavior (Driskell et al., 2008).

A systematic review of moderators in school-based interventions aimed at energy balance behaviors found that girls tended to respond better to interventions than boys (Yildirim et al., 2011). The authors suggest numerous reasons for this finding, including the tendency for boys to be more physically active, and therefore have less room for improvement, and the tendency for girls to have more concerns about body weight and body image, leading to more interest in intervention material. Other potential explanations include differences in social desirability, understanding of intervention materials, perceived and practical barriers, and perceived benefits.

School-based health behavior interventions

Adolescence is a time with great potential for health promotion, but is accompanied by great risk, underlining the need for early intervention. In an effort to promote health behaviors, many school-based energy balance interventions have focused on energy balance and substance use behavior, presenting vital opportunities for health promotion and risk reduction in young people. Unfortunately, energy balance interventions in adolescents are few and have been met with mixed success (De Bourdeaudhuij et al., 2010; Ezendam et al., 2012; Lubans et al., 2009; Patrick et al., 2006; van Stralen et al., 2011). Successful and effective behavioral interventions may serve to prevent smoking prevalence in adolescents, reduce daily smokers in young adulthood, increase quality-adjusted years of life, and reduce medical costs later in life (Wang & Michael, 2014). However, some substance abuse prevention studies have found no significant (Faggiano et al., 2010; Malmberg et al., 2015) or negative (Sloboda et al., 2009) treatment effects. A review of school-based interventions discusses successful components, such as booster sessions, normative feedback, programs delivered by mental health professional, and programs with multiple levels of interventions (i.e. family, school, community), but also identified characteristics associated with lower intervention success, such as a large scale programs and programs that focus only on smoking or only on alcohol (Nsimba & Amos, 2012).

A recent school-based intervention trial reported findings from a randomized TTM computer-delivered, multiple behavior intervention in middle school students (Velicer et al., 2013). The intervention was conducted to address major gaps in prevention research by targeting multiple risk behaviors, including energy balance and substance use prevention. Students were randomly assigned to either a smoking and alcohol prevention program or an energy balance program, which targeted physical activity, fruit and vegetable consumption, and limited TV viewing, with each condition serving as a comparison condition for the other. The study found that students in the energy balance intervention effectively initiated and maintained energy balance behaviors in addition to reducing smoking and alcohol acquisition, despite no direct treatment for smoking and alcohol prevention. Data from this study form the foundation of this dissertation.

Transtheoretical Model of behavior change

Briefly, psychological interventions applying the TTM of behavior change purport that people vary in their general readiness to change, as well as their attitudes and beliefs about that change (Prochaska, 1983). Intentional behavior change is traditionally represented as a progression through the five ordered Stages of Change: Precontemplation (PC), Contemplation (C), Preparation (P), Action (A), and Maintenance (M) (Prochaska, Redding, & Evers, 2008; Prochaska & Velicer, 1997; Prochaska, Wright, & Velicer, 2008; Velicer et al., 2000). Forward movement through these stages is considered progression towards maintaining healthy behaviors. Individuals may progress and/or regress numerous times during the behavior change process and is thus not necessarily considered to be a straight and linear trajectory. Stage movement has been found to be related to an individual's Decisional Balance, (the Pros and Cons of behavior change; Velicer, DiClemente, Prochaska, & Brandenburg, 1985), Self-Efficacy (the degree of confidence in maintaining change or resisting temptation; Velicer, DiClemente, Rossi, & Prochaska, 1990), and the Processes of Change (cognitive, emotional, and behavioral adjustments that help explain how change occurs; Prochaska, 1983; Prochaska, Redding, et al., 2008; Prochaska & Velicer, 1997). These different constructs have been found to be important at different time points relative to an individual's readiness to engage in behavior change. For example, individuals in PC weigh the Cons higher than the Pros, while the opposite is true for participants in Action (Hall & Rossi, 2008; Prochaska, 1994). Further, Self-Efficacy has been found to increase as individuals progress towards Maintenance (Prochaska, Redding, et al., 2008; Redding, Maddock, & Rossi, 2006).

Longitudinal research has established that TTM constructs are dynamic and that behavioral interventions promote stage progression (Prochaska, Velicer, Guadagnoli, Rossi, & DiClemente, 1991). Given its qualitative nature, stage movement is both discrete and dynamic, as people often progress and regress through the stages during the behavior change process. This discrete, stage-sequential framework is ideal for the application of Latent Transition Analysis (LTA), a latent variable model that utilizes Markov modeling and autoregressive techniques to predict the probability of temporal movement among discrete categories of people conditional on previous time points (Collins & Lanza, 2010; Velicer, Martin, & Collins, 1996). This framework highlights the change process and emphasizes the notion that stages represent temporary statuses in which individuals may transition in and out of over time. See Appendix B for a detailed overview of the LTA model.

APPENDIX B: LATENT TRANSITION ANALYSIS

Latent Transition Analysis (LTA) is a longitudinal extension of Latent Class Analysis (LCA), a latent variable measurement model using observed discrete variables to produce categorical latent classes (Collins & Lanza, 2010). In contrast to factor analysis, which produces a continuous latent variable by reducing dimensionality in the variable space, LCA reduces a population into mutually exclusive and exhaustive categorical subgroups. LTA builds off of LCA by predicting the probability of temporal movement among classes conditional on previous class membership. In the context of determining longitudinal change in TTM-stage variables, LTA is an appropriate method due to the focus on discrete, rather than continuous, change. Therefore, the work contained in this dissertation aims to use LTA to characterize longitudinal patterns of change in TTM Stage of Change movement across intervention conditions for five health behaviors in adolescents from grades six to nine.

The basic LTA model predicts the probability of stage membership and movement over time conditional on previous stage membership (Collins & Lanza, 2010). LTA contains both a measurement and structural component. The measurement component characterizes the discrete latent classes and the structural component determines the probabilities of status membership and transition. The structural component relies on autoregressive techniques to acknowledge a stochastic process in which repeated measures are linearly dependent on their own previous values. The LTA model is constructed using information from a contingency table containing cross tabulations of discrete measures at each time point. Consequently, the object for model fitting is to find a model that fits the patterns in contingency data well.

Three sets of parameters are estimated using the Expectation-Maximization (EM) algorithm: latent status prevalences (δ), transition probabilities (τ), and item-response probabilities (ϱ). δ estimates represent the proportion of status membership at time *t*. Latent statuses are mutually exclusive and exhaustive such that every individual is placed in only one group at each time point. τ estimates represent the probability of transitioning to a given status at time *t,* conditional on status at time *t-1* (for a first order model). The τ parameters reveal the underlying process of change and elucidate stage progression, regression, or stability. Finally, ϱ estimates take into account measurement error and represent the probability of a response for a particular item, conditional on latent class membership at a specific time point. Thus, similar to factor loadings in structural equation modeling, ϱ's form the basis of latent status separation as they are used to indicate patterns of responses among discrete variables across time based on latent status membership. Unlike factor loadings, however, ϱ's are probabilities and are scaled differently. Values close to 0 or 1 indicate latent status membership while values that are close to one divided by the number of response patterns indicates chance (Velicer, Martin, & Collins, 1996). When measurement error in classification is not estimated the ϱ matrix becomes an identity matrix and the model reduces to a manifest model (Kaplan, 2008).

Extensions of LTA

The basic LTA model can be extended to a multiple-groups analysis through the inclusion of a grouping variable. This results in estimation of model parameters conditional on observed group membership. Covariates can also be incorporated into the model using logistic link function (Lanza & Collins, 2008). A covariate can be time dependent or time independent and is be specified as a predictor of latent status membership at the first time point and/or as a predictor of transition probabilities. Inclusion of covariates results in the estimation of additional parameters, including a set of beta (β) parameters representing logistic regression coefficients. In the covariate model, δ and τ parameters are estimated as a function of β and the covariates.

Model Fit and Selection

Model fit is assessed using several available criteria. The Goodness of Fit statistic, G^2, is approximately distributed as a χ^2 and can also be used to compare alternative models (Collins & Lanza, 2010; Velicer et al., 1996). Nested models can be compared using log likelihood ratio G^2 difference tests, which is calculated by the differences in G^2 of two competing models relative to their difference in degrees of freedom. However, tests based on the χ^2 distribution have a number of identified limitations, such at sensitivity to sample size, failure of the noncentral χ^2 in applied settings, reliance on the nil hypothesis testing framework, nor does it incorporate information about model parsimony (Preacher & Merkle, 2012). The Akaike Information Criteria (AIC; (Akaike, 1973)), which penalizes model complexity, and the Bayesian Information Criterion (BIC; (Atkinson, 1978)), which penalizes more heavily and includes penalty for large sample size, are also commonly used. Both of these information criteria have been criticized for not being valid in real word data and for underfitting or overfitting data under certain conditions (Dziak, Coffman, Lanza, &

Li, 2012). However, it is largely unknown how any of these criteria of model fit perform in large, complex LTA models (Lanza & Bray, 2010).

LTA can be conducted using the SAS Macro for PROC LTA (PROC LCA & PROC LTA [Version 1.3.0], 2013). Missing data is handled using the full-information maximum likelihood technique. In order to conduct model comparison tests, matrices containing start values and parameter restrictions can be specified to aid in model convergence and to constrain certain parameters to equivalence. Syntax containing starting values and parameter restrictions for all models in this dissertation are available upon request. Parameter restrictions are used to specify nested models and test specific hypotheses about model equivalent across groups in comparison to a baseline model.

TTM research using LTA

Due to the categorical nature of LTA, the method lends itself well to examination of stage transitions using the TTM. LTA has been used to determine stage of change transitions in an adult sample for smoking cessation stages (Martin et al., 1996). In this study, three stage-based LTA models for various patterns of stage movement were compared. The best fitting model was one in which both progression and regression described stage change. In this model, progression was found to be more likely than regression and a one-stage progression was more likely that a two-stage progression between successive time points. The model also demonstrated a great deal of stability in transitions, with the highest stability of staying in Contemplation and the lowest of staying in Action. This study was specific to adult smokers measured in six-month increments and did not incorporate intervention effects.

A similar study used LTA to compare both cessation and acquisition stages for smoking in an adolescent sample (Guo et al., 2009). Findings from this study indicated support for a free transition model for smoking cessation, compared to constrained movement models found in Martin et al. (1996), indicating a great deal of variability in stage movement. Findings also supported a free transition model for smoking acquisition stages, but demonstrated greater stability than the cessation stages. The authors concluded that there was no overall support for orderly or sequential stage movement (Guo et al., 2009).

To date, few published studies have used LTA to examine stage of change transitions and even fewer have examined how behavioral interventions impact these transitions. Studies applying LTA to TTM stages of change have been primarily focused on smoking behavior (Guo et al., 2009; Händel et al., 2009; Schumann et al., 2002), with one study that focused on classification rates in the staging algorithm for physical activity (Dishman et al., 2009) and one applying LTA to changes in condom use (Evers, Harlow, Redding, & LaForge, 1998). Thus, the characterization of discrete stage change using the TTM has been largely understudied across different behavioral domains. Replication of smoking transitions is needed to confirm previous findings by Martin et al. (1996) in adults and Guo et al. (2009) in adolescents while a thorough examination of the impact of intervention on the change pattern is crucial to the understanding of behavior change.

The overarching goal of this dissertation is to broaden the current understanding of patterns of TTM stage change by examining transitions in energy balance and substance use behaviors. A major contribution includes the examination of three previously unstudied behaviors (i.e. alcohol use, diet, and TV viewing). Other major contributions of this work includes the focus on a model comparison approach to determine the best pattern of stage change over time, the stability of model parameters over time, and the effects of intervention condition and gender on model parameters. Appendix C presents a summary of findings from the three resulting manuscripts.

APPENDIX C: OVERVIEW AND DISCUSSION

The primary aim of the work contained in this dissertation aims to characterize and advance the understanding of Stage of Change transitions, with emphasis on patterns of change over time, across intervention condition, and across multiple behaviors. Latent Transition Analysis was used to determine probabilities of stage membership and transitions in three studies using data from a school-based Transtheoretical Model multiple health intervention in adolescents. Below is a summary of major findings from each of the three studies, followed by a general discussion and final remarks.

Manuscript 1: Intervention effects on stage of change membership and transitions among adolescent energy balance behaviors

The first study focused on determining stage of change transitions in three energy balance behaviors (e.g. physical activity, fruit and vegetable consumption, and TV viewing) across time, intervention condition, and behavior. LTA models determined stage membership and transitions for adolescents' readiness to engage in healthy behavior change.

Comparison across time. Results from comparison of stage movement pattern models revealed that a free stage movement transition model was favored compared to one, two-, or three-stage movement forward and backward patterns for all three behaviors. An examination of transition probabilities from the freely estimated stage movement models revealed that there were higher probabilities of staying in the same stage than transitioning, and that the probability of stage movement beyond one or two stages was very low.

In addition, models for all behaviors that examined the stability of transition probabilities over time tended to favor stable transition models for the comparison intervention and dynamic transition models for the energy balance intervention. This was evident when models containing equivalent tau matrices from grades six to nine did not significantly worsen model fit, compared to a free transition model, in the comparison condition but did worsen fit in the intervention condition.

Comparison across intervention condition. Intervention effects on stage transitions for all behaviors resulted in nonequivalent model parameters across intervention condition from grades six through eight, but equivalent transition parameter from grades eight to nine. An interesting pattern emerged such that no students in the comparison intervention moved from pre-action stages (i.e. PC, C, PR) to Maintenance (M) during the course of the study. This pattern was also observed in the intervention condition, but only during the transition from grades eight to nine, which coincides with the post-intervention follow-up period. This finding provides evidence for the ability of the energy balance intervention condition to successfully promote stage movement into M, but that the effect seemed to disappear after eighth grade, which coincided with the last intervention time point.

Comparison across behavior. Finally, models using behavior as a grouping variable determined that neither baseline stage membership nor transitions were equivalent across behaviors for each intervention condition. This suggests that the pattern of change specific to each intervention condition varies across behavior paradigm. Differences in transition probability estimates did not exceed 0.30, with most below 0.20.

Conclusion. Each behavior exhibited unique baseline stage distribution, with students having a higher probability of being in M for exercise, high probabilities of being in PR, followed by C and M for fruit and vegetable consumption, and high probabilities of being in PC or M for TV viewing. Each behavior also exhibited unique patterns of stage transitions, though all demonstrated more positive intervention effects (i.e. stage progression towards M) in the intervention condition than in the comparison intervention. These effects also appeared to diminish for all behaviors after eighth grade.

Manuscript 2: Intervention effects on stage of change membership and transitions among adolescent smoking and alcohol use acquisition

The focus of this study was to examine behavior acquisition for smoking and alcohol use. LTA was used to determine acquisition stage membership and transitions using models that incorporated an absorbing class of users, in which students had a zero probability of transitioning out of once entered (i.e. once a student was considered a smoker, they could not longer be considered in the prevention framework and were instead provided intervention feedback on smoking cessation). Emphasis was placed on determining pattern of change over time and across intervention condition.

Comparison across time. Results from comparison of stage movement pattern models revealed that a free stage movement transition model was favored compared to one- or two-stage movement forward and backward patterns for both smoking and alcohol. An examination of the free stage movement models revealed that, overwhelmingly, the highest probabilities were for staying in or transitioning into aPC, with some movement among aPC, aC, and aPR and some movement into smoker/drinker status. Probability of movement directly from aPC to drinker/smoker tended to be low (<6%), revealing that most transitions into smoker/drinker status tended to be from aC or aPR.

Results comparing the temporal stability of transitions were mixed. For smoking, tau parameters in the substance use intervention condition across were shown to be equivalent from grades six to nine, indicating stable transition estimates that did not change much over the course of the intervention or after the intervention had completed. In the comparison condition, transitions from grades seven to nine were found equivalent, indicating that the transition probabilities from grades six to seven were different than transitions from grades seven through nine. For alcohol, transitions in the substance use intervention from grades seven to nine were found equivalent, and transitions in the comparison condition were nonequivalent across all grades.

Comparison across intervention condition. For smoking, transitions from grades six to seven were nonequivalent across groups, but were for transitions from grades seven to nine. For alcohol use, transitions across grades six and eight were not equivalent across groups, but were for grades eight to nine.

Conclusion. In sixth grade, nonsmoking/nondrinking students had a 98-99% probability of reporting not planning to try smoking or drinking, yet by the end of the study, both intervention groups had a 11% and 9% probability of becoming ever-smokers and a 19% and 13% probability of becoming ever-drinkers, in the substance use and comparison interventions, respectively. Findings from this study demonstrated that students in aPC were less likely to try smoking or drinking than students in aC or aPR and that both interventions resulted in generally more backwards movement toward aPC (i.e. prevention) than movement toward ever-smoking/drinking (i.e. substance use acquisition). Contrary to the original hypothesis, the comparison intervention resulted in fewer of students transitioning to trying smoking or drinking than the substance use intervention. Both interventions, however, appear to have provided protective effects on smoking and alcohol use acquisition in adolescents, in comparison to data from nonparticipating schools (Velicer et al., 2013).

Manuscript 3: Gender differences in stage of change membership and transitions among adolescent physical activity and fruit and vegetable consumption

In the final study, gender differences in TTM stage membership and transition for physical activity and fruit and vegetable consumption were examined using two approaches. First, a multiple-group LTA model was fit using gender as a grouping variable to determine gender differences in each of the intervention conditions separately. Then, gender was entered as a covariate in a multiple-group model binary logistic regression LTA using intervention condition as a grouping variable.

Intervention specific effects across gender. Multiple-group models provided parameter estimates conditional on gender and demonstrated differences in baseline stage membership and transitions within each intervention for both physical activity and fruit and vegetable consumption. For both behaviors, models indicated differences in baseline (i.e. sixth grade) stage distribution across gender for each of the intervention conditions. For physical activity, models demonstrated gender differences in transition probabilities for both intervention groups. For fruit and vegetable consumption, most models demonstrated gender differences in transition probabilities; however, the transitions from seventh to eighth grade in the intervention, as well as the transition from sixth to seventh grade in the comparison conditions were found equivalent.

In sum, at baseline, males had a higher probability of being in M for physical activity than females. Examination of the stage membership and transition parameters revealed that females tended to have lower rates of staying in and transitioning into M. Models investigating stage of change for fruit and vegetable consumption revealed slightly different patterns than physical activity. At baseline, males had a higher probability of being in PC than females. Examination of the stage membership and transition parameters also revealed that females tended to have lower rates of membership in PC and that membership in PC was higher for both males and females in the SP intervention.

Gender effects across intervention condition. Multiple-group binary logistic transition models further supported the differential effects of gender on stage membership and transitions across intervention condition. For physical activity, males were more likely than females to be in M at baseline compared to all other stages for both intervention groups. Males also demonstrated a tendency towards higher odds of transitioning to M, especially in the intervention, compared to females. For fruit and vegetable consumption, males were more likely than females to be in PC at baseline compared to all other stages for both intervention groups. Contrary to the goal of the intervention, males also demonstrated a tendency towards higher odds of transitioning back to PC from A and M in the intervention.

Conclusion. Collectively, the results from this study indicate that males and female adolescents differ in their readiness to engage in and maintain physical activity and fruit and vegetable consumption behaviors, and that they may experience differential intervention effects. About half of all students report being in M for physical activity in sixth grade. However, males had a higher probability of being in M for physical activity than females. Examination of the stage membership and transition parameters revealed that females tended to have lower rates of staying in and transitioning into M. Gender differences were reiterated in the covariate models in that males were more likely than females to be in M at baseline compared to all other stages for both intervention groups. Males also demonstrated a tendency towards higher odds of transitioning to M, especially in the energy balance intervention, compared to females. Female students had higher rates of being in PR than males and lower odds of transitioning to M, suggesting that female students are more ready to change but may have a harder time making the changes relative to the male students.

Models investigating stage of change for fruit and vegetable consumption revealed slightly different patterns than physical activity. The stage distribution for this behavior was markedly different. At baseline, males had a higher probability of being in PC than females. This finding was also supported in the covariate models such that males were more likely than females to be in PC at baseline compared to all other stages for both intervention groups. Contrary to the goal of the intervention, males also demonstrated a tendency towards higher odds of transitioning back to PC from A and M in the energy balance intervention. Examination of the stage membership and transition parameters also revealed that females tended to have lower rates of membership in PC and that membership in PC was higher for both males and females in the comparison intervention.

General Discussion

The work contained herein represents the first study to determine TTM stage of change transitions for diet and sedentary behaviors (i.e. TV viewing) as well as for alcohol use acquisition. It also provides TTM stage transitions for smoking acquisition and physical activity in adolescents, which have examined in the past but not in an adolescent population. It also represents the first application of multiple-group LTA to test hypotheses about equivalence of delta and tau parameters across TTM intervention conditions and across behaviors and is the first study to use LTA to examine gender differences in TTM stage transitions across intervention condition.

Limitations. A number of limitations must be considered in light of the findings in this dissertation. One major limitation was that the intervention did not include a true no-treatment control group, preventing the ability to model natural or normative changes in adolescent behavior. Without an index of natural change in behaviors in relation to stage change as students move from sixth to ninth grade, it is hard to determine whether the interventions provided protective benefits for specific behaviors above what would normally happen without intervention. Consideration of the issue regarding a lack of a no-treatment control group is also described in the original study, which highlights the choice in a two-treatment control comparison trial as more cost effective, maximized school participation, and met curriculum demands of participating schools (Velicer et al., 2013). In addition, though students were nested within schools, analyses did not account for potential school-level effects. Future studies would benefit from examination of a multilevel LTA (Asparouhov and Muthen, 2008). Finally, there was no examination of cross-behavioral interactions that may promote stage change above and beyond what intervention on a single behavior may produce.

Another major limitation toward interpreting model comparison results in this study is the lack in a good index of model fit. The fit indices currently available for PROC LTA in SAS (i.e. G^2, AIC, BIC) have been criticized for their assumptions and reliability in real world data (Dziak et al., 2012). Due to the nature of LTA, the models tested in this paper all had extremely large numbers of estimated parameters. It is largely unknown how well these indices perform with complex LTA models. Further, though simulation studies have demonstrated that sparseness in cell counts do not greatly bias parameter estimates (Collins and Wugalter, 1992) for some transitions that may limit the robustness of model parameters, it is noted that there was low membership in some of the groups estimated by LTA models.

In addition, all three studies to note is the fact that stage was treated as a single indicator for each latent status measured without error. LTA inherently contains the capability to incorporate measurement error into the classification of homogenous subgroups. However, although the TTM staging algorithm is designed to reduce potential stage misclassifications, a certain degree of error potentially remains in the staging classification algorithm since self-reported single items represent each stage. Since all measures in the three studies relied on self-report, a degree of measurement error may remain.

Future studies. Findings from these studies can be use to inform future intervention design in numerous ways. First, results from this dissertation can be used to inform interventions by providing information on what subgroups of students may need specific types of tailored or targeted feedback. For example, given the tendency for high probabilities of staying in PC, interventions may strive to identify individuals who are likely to remain in PC and provide alternative suggestions or guidance. For example, someone who is not ready to change and remains that way consistently may have different needs than an individual who are likely to transition more. Similarly, a person who is unstable in A or M may need more feedback or support than a person who is consistently in M and does not tend to waver. In this way, interventions may be developed to be sensitive not only to whether a person is ready to change at a given time, but also to whether they tend to remain stable or fluctuate in their readiness. Participants who remain stable (i.e. stayers) and participants who tend to transition (i.e. movers) can be modeled using a higher-order class. Differences in behavioral outcomes, as well as other TTM constructs such as Self-Efficacy and Decisional Balance, could be examined.

Given the significant gender differences demonstrated in Manuscript 3, future interventions may consider providing gender-targeted feedback for behaviors that exhibit known gender disparities. For example, since females tend to have lower transitions into M for physical activity, interventions could provide additional support or tips for adolescent girls to help them maintain their physical activity. Similarly, given the finding that males had higher probabilities of regressing back into PC from A/M, future interventions may want to provide more support towards maintenance for healthy eating behaviors for boys. Future interventions may also consider exploring the differential effects of other demographic factors, such as race/ethnicity and socioeconomic status.

Finally, interventions should be designed to replicate findings from this paper to help shed light on sample specific effects versus consistent intervention effects. Hypotheses regarding specific stage transitions may guide design and analytic approach for intervention research using a model comparison approach. For example, future studies could hypothesize that a successful intervention should result in more transitions into A/M than a comparison intervention or control group and less backwards transitions toward PC or toward user status in the acquisition prevention framework rather than reliance on traditions point prevalence outcomes like number of minutes of exercise or number of cigarettes. In this way, focus is shifted towards impacting the process of behavior change, which generally requires a lifetime of commitment and does not end simply with the end of a research study.

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